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Office of Solid Waste and
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Washington DC 20460

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EPA

Technical Guidance Document:

The Fabrication of Polyethylene FML Field Seams

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THE FABRICATION OF POLYETHYLENE FML FIELD SEAMS

Office of Solid Waste and Emergency Response
U.S. Environmental Protection Agency
Washington, DC 20460

In cooperation with

RISK REDUCTION ENGINEERING LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

The preparation of this document has been funded wholly by the United States Environmental Protection Agency. It has been subjected to the Agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of solid and hazardous wastes. These materials, if improperly dealt with, can threaten both public health and the environment. Abandoned waste sites and accidental releases of toxic and hazardous substances to the environment also have important environmental and public health implications. The Risk Reduction Engineering Laboratory assists in providing an authoritative and defensible engineering basis for assessing and solving these problems. Its products support the policies, programs, and regulations of the U.S. Environmental Protection Agency; the permitting and other responsibilities of State and local governments; and the needs of both large and small businesses in handling their wastes responsibility and economically.

This document provides guidance for construction quality control and construction quality assurance inspectors and related personnel as to the proper techniques for making field seams on polyethylene flexible membrane liners (FML's). It focuses specifically on the three most widely used techniques; extrusion fillet, extrusion flat and hot wedge fabrication methods. The presentation of each of these methods details FML preparation in advance of seaming, equipment preparation, the actual seaming process and finally the activities to be performed after the seaming is completed. Rationale is provided for the various conditions and limitations that are suggested. A glossary of terms relevant to fabrication of polyethylene FML field seams is given at the end of the document.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

PREFACE

Subtitle C of the Resource Conservation and Recovery Act (RCRA) requires the U.S. Environmental Protection Agency (EPA) to establish a Federal hazardous waste management program. This program must ensure that hazardous wastes are handled safely from generation until final disposition. EPA issued a series of hazardous waste regulations under Subtitle C of RCRA that are published in Title 40 Code of Federal Regulations (40 CFR). The principal 40 CFR Part 264 and 265 regulations were issued on July 26, 1982 for treatment, storage, and disposal (TSD) facilities and establish performance standards for hazardous waste landfills, surface impoundments, land treatment units, and waste piles. The regulations have been amended several times since then.

In support of the regulations, EPA has been developing three types of documents to assist preparers and reviewers of RCRA permit applications for hazardous waste TSD facilities. These include RCRA Technical Guidance Documents, Permit Guidance Manuals, and Technical Resource Documents (TRDs).

RCRA Technical Guidance Documents, such as this one, present design and operating parameters or design evaluation techniques that generally comply with, or demonstrate compliance with, the Design and Operating Requirements and the Closure and Post-Closure Requirements of 40 CFR Part 264.

The Permit Guidance Manuals are being developed to describe the permit application information the Agency seeks, and to provide guidance to applicants and permit writers in addressing information requirements. These manuals will include a discussion of each set of specifications that must be considered for inclusion in the permit.

The Technical Resource Documents present summaries of state-of-the-art technologies and evaluation techniques determined by the Agency to constitute good engineering designs, practices, and procedures. They support the RCRA Technical Guidance Documents and Permit Guidance Manuals in certain areas (i.e., liners, leachate management, final covers, and water balance) by describing current technologies and methods for designing hazardous waste facilities, or for evaluating the performance of a facility design. Although emphasis is given to hazardous waste facilities, the information presented in these TRDs may be used for designing and operating nonhazardous waste TSD facilities as well. Whereas the RCRA Technical Guidance Documents and Permit Guidance Manuals are directly related to the regulations, the information in these TRDs covers a broader perspective and should not be used to interpret the requirements of the regulations.

This document is a Technical Guidance Document prepared by the Risk Reduction Engineering Laboratory of EPA's Office of Research and Development in cooperation with the Office of Solid Waste and Emergency Response. The document has undergone extensive technical review and has been revised accordingly. With the issuance of this document, all previous drafts are obsolete and should be discarded.

Comments are welcome at any time on the accuracy and usefulness of the information in this document. Comments will be evaluated, and suggestions will be incorporated, wherever feasible, before publication of any future revisions. Written comments should be addressed to EPA RCRA Docket (OS-305), 401 M Street S.W., Washington, DC 20460. The document for which comments are being provided should be identified by title and number.

ABSTRACT

This technical guidance document is meant to augment the numerous construction quality control and construction quality assurance (CQC and CQA) guidelines that are presently available for high density polyethylene (HDPE) liner installation and inspection. In general, the tone of these existing documents is to allow the installer almost complete freedom in making seams with the only conditions being that they pass;

(a) destructive shear and peel tests to a stipulated strength, and
(b) selected nondestructive tests, e.g., vacuum box testing

However, there is a long-term concern regarding seam integrity which is not addressed by following this course of action. Simply expressed, it appears as though the long-term service life of some HDPE liners is compromised when seams are made improperly. This comes about by overgrinding, overheating, placing new welds directly over older welds, or simply by poor workmanship.

By developing a document somewhere between the typical CQC/CQA document and an installer's training manual, i.e., a "standard-of-practice", it is hoped that the above negative features of seam making can be avoided. It is hoped to provide deeper insight for an inspector as to what the installer is trying to accomplish. At the same time it might be also helpful to the installer in recognizing that others have a vested interest in their specific activity. After some introductory material, the manual is focused toward three types of field seams used for fabricating field seams in HDPE liners:

- extrusion fillet seams
- extrusion flat seams
- hot wedge seams

Additional seam types will be added to future editions of this manual as considered desirable and necessary.

CONTENTS

FIGURES

FIGURES (continued)

TABLES

ACKNOWLEDGMENT

This technical guidance document grew out of a series of meetings of the various HDPE manufacturers of FML's who are member organizations of the Geosynthetic Research Institute (GRI) of Drexel University. Later drafts were reviewed by the various polyethylene resin producers and the consulting engineering and testing firms within GRI. Still later drafts were reviewed by several private owners of waste containment facilities. Robert M. Koerner was the project coordinator who extends sincere appreciation for the excellent cooperation and openness of this group of organizations in sharing information and critiquing the various drafts of the document.

The EPA project manager of this technical guidance document was Robert E. Landreth with the assistance of David A. Carson.

1. INTRODUCTION

The lining of hazardous and non-hazardous solid waste landfills, surface impoundments and waste piles is a critical component in the prevention of contamination of subsurface soil and groundwater. When the contained solid or liquid is of a hazardous nature, every aspect of the lining system must undergo the closest possible scrutiny. The need for both construction quality control (CQC) and construction quality assurance (CQA) becomes requisite at many facilities. With an extremely large number of facilities currently planned and under construction there also comes many organizations with a lack of experience in specialized topics. Certainly an area such as flexible membrane liners (FMLs) made from polyethylene (PE) falls into this category. Many inspection firms entering into this area have had little formal training or practical experience in dealing with polyethylene FML's. This is not to say that experienced firms are not available; they are indeed, and are very active in providing excellent inspection services. However, there appears to be a need to have a primer on certain aspects of FML installation and this document will hopefully fill part of this need.

As will be seen, this manual is very narrowly focused, addressing only one part of the total liner system, that is the seams. Furthermore, only field seams of polyethylene FMLs will be addressed in this report. Still further, it is the making (or fabrication) of the seams which will be the focus, not their destructive or nondestructive testing. There are numerous excellent documents on this latter topic, see, for example, Frobel[1], Lord, et al.[2], Overmann[3] and Richardson[4].

2. CONSTRUCTION QUALITY ASSURANCE CONCEPTS

As written in EPA Report 600/2-88/052 entitled "Lining of Waste Containment and other Impoundment Facilities"(5) construction quality assurance (CQA) is a planned system of activities that provides assurance that the unit is constructed as specified in the design. Thus, CQA refers to those activities initiated by the owner of the facility that ensure that the construction of the entire facility, including manufacture, fabrication, and installation of the various components of the lining system, meets design specifications and performance requirements. The activities include inspections, verifications, audits, and evaluations of materials and workmanship necessary to determine and document the quality of the constructed facility. These activities are often performed by a third-party quality assurance team that is independent of the designer, manufacturer, fabricator, installer, operator and owner to ensure impartiality.

CQA activities should be differentiated from construction quality control (CQC) activities which include those activities and procedures initiated by the designer, manufacturer, fabricator, installer, or contractor(s) necessary to control the quality of the constructed or installed component and to ensure that specifications are being met. Even though the CQC activities will overlap with those performed in fulfillment of the CQA plan, the two activities are often performed by independent organizations.

Regarding the elements of a CQA plan, EPA Report 530-SW-86-031 entitled "Construction Quality Assurance for Hazardous Waste and Land Disposal Facilities"(6) presents the following key elements

- Responsibility and Authority -- The responsibility and authority of organizations and personnel involved in permitting, designing, and constructing the facility should be described in the CQA plan.

- CQA Personnel Qualifications -- The qualifications of the CQA officer and supporting CQA inspection personnel should be presented in the CQA plan.

- Inspection Activities -- The observations and tests that will be used to ensure that the construction or installation meets or exceeds all design criteria, plans, and specifications for each component should be described in the CQA plan.

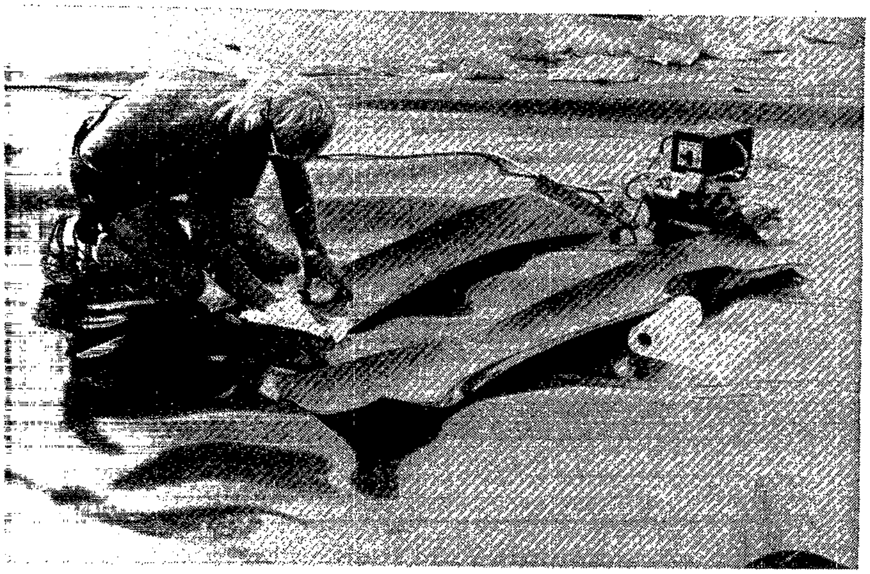
- Sampling Strategies -- The sampling activities, sample size, methods for determining sample locations, frequency of sampling, acceptance and rejection criteria, and methods for ensuring that corrective measures are implemented should be presented in the CQA plan.

- Documentation -- Reporting requirements for CQA activities should be described in detail in the CQA plan.

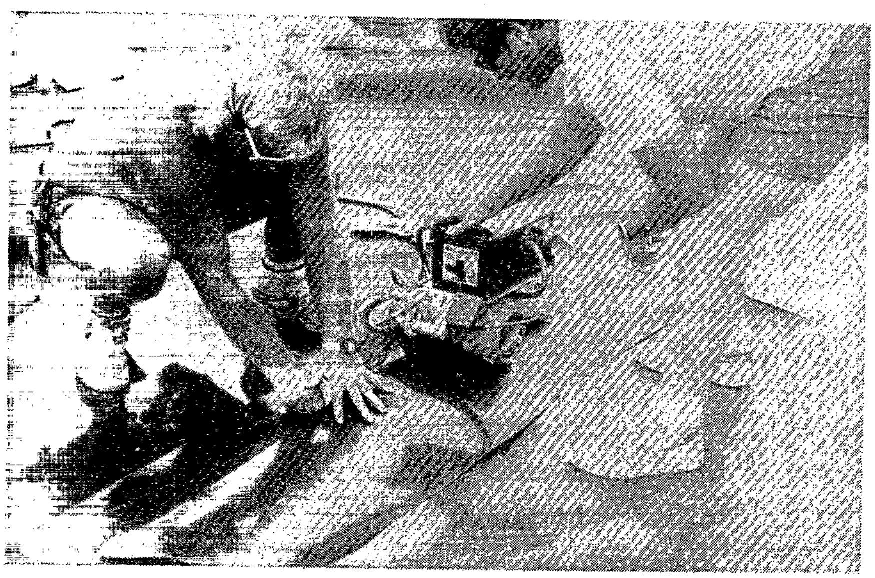
This particular manual focuses on one specific aspect of CQA "inspection activities", namely the inspection of field seams used in the joining of polyethylene FML's.

One item that is in many CQA documents is the requirement of making "test welds" or "test strips" on a periodic basis. This procedure is often stipulated to be at least every four hours, every time personnel are changed or at the request of the field inspector. This practice is highly recommended and must be a part of standard practice for the seaming of all FML's, including those made from polyethylene. The ultimate purpose of such tests is to establish proper seaming temperatures, pressure and rates, along with the necessary FML preparation procedures and subsequent seam evaluation. Photographs of the preparation of such "test strips" follow in Figure 1. Figure 1(a) shows the two FML pieces to be seamed being cleaned and properly aligned, 1(b) shows the actual test strip being seamed, 1(c) shows the sampling of the test strip for subsequent destructive testing, and 1(d) shows the individual samples cut from the test strip being identified.

Test strips of the type shown in Figure 1 are approximately 5 ft. long for extrusion seams, to 10 ft. long for hot wedge seams. The seam is centered lengthwise between the two sheets to be joined. After fabrication of the seam, 1.0 in. wide seam specimens are cut from the completed test strip and evaluated in the field using a portable tensiometer. Both shear and peel tests are conducted. If a test seam fails to meet field seam specifications, the seaming apparatus and/or seamer shall not be accepted and shall not be used for seaming until the deficiencies are corrected and two consecutive successful full test seams are achieved. As seen in Figure 1(d), the remainder of the test strip is cut into pieces for laboratory testing and retention by the various parties involved, e.g., agency, owner, manufacturer, CQC and/or CQA organizations.

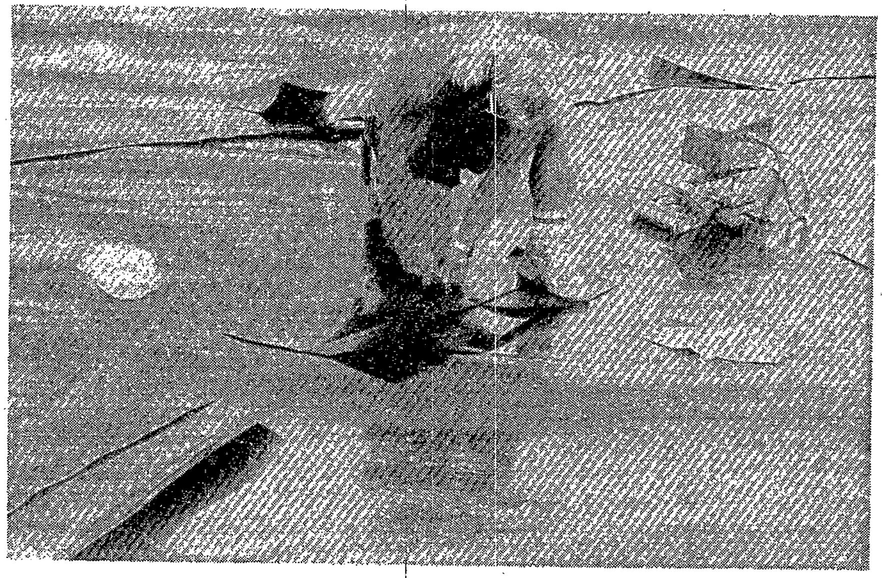


(a) Two Sheets of Liner Being Cleaned and Prepared for Trial Seaming

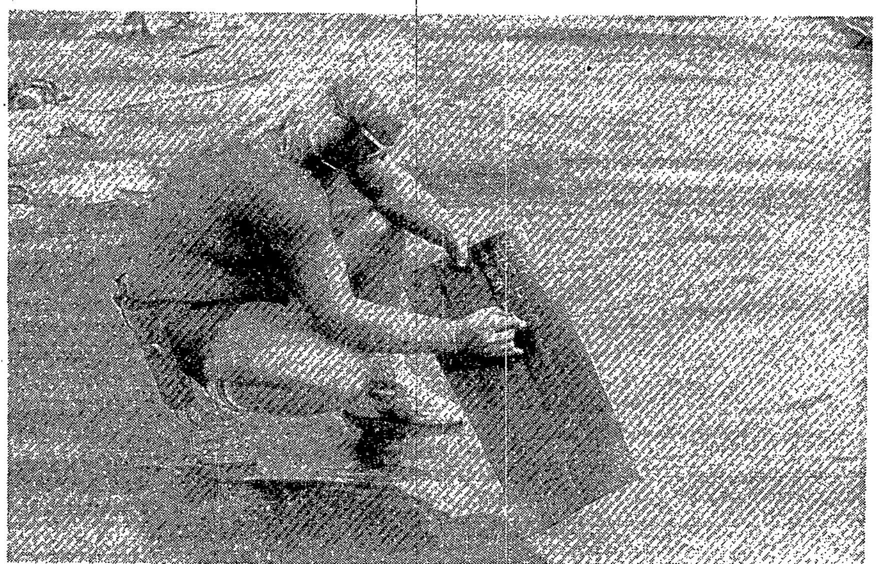


(b) The Two Sheets Being Seamed Together Thereby Forming the Test Strip

Figure 1. Fabrication of FML Seam Test Strip



(c) The Completed Test Strip Being Cut into Individual Samples for Subsequent Inspection and Destructive Testing



(d) Marking the Test Strip Samples for Identification and Records

Figure 1. (Continued)

3. POLYETHYLENE FML's

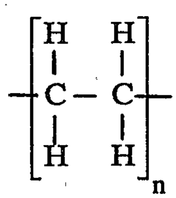
FML's can be made from a wide variety of polymeric materials. Table 1 below illustrates the three different classes of FML's along with the various additives that are often used. It is based on 100 parts by weight of the particular polymer resin or alloy with other materials being added as would be practiced in the actual compounding of the final product.

TABLE 1. MAJOR COMPONENTS IN VARIOUS TYPES OF POLYMERIC FML's, AFTER HAXO[7]

Component	Composition in Parts by Weight		
	Thermoset	Thermoplastic	Semicrystalline
Polymer or Alloy	100	100	100
Oil, Plasticizer or Processing Agent	5-40	5-55	0-10
Fillers			
carbon black	5-40	5-40	2-5
inorganics	5-40	5-40	--
Antidegradants	1-2	1-2	1
Crosslinking			
inorganic	5-9	0-5	--
sulfur	5-9	--	--

Due in large part to the lack of ingredients other than the polymer or alloy itself, the semicrystalline material "polyethylene" is often used for liners beneath hazardous solid and liquid waste facilities. It should be noted, however, that polyethylene is both thermoplastic and semicrystalline but the latter property gives it its distinction. As seen below, polyethylene has a very simple repeating molecular unit giving rise to a long chain, high molecular weight, structure.

REPEATING POLYTHEYLENE MOLECULE



Note that the above repeating molecule is the general form for low-, medium-, and high-density polyethylene. To distinguish between the various types, the degree of crystallinity and extent of branching must be known; see Table 2 for such a classification based on resin density.[8] For greater detail on polyethylene classifications versus property values see reference #9.

TABLE 2. CLASSIFICATION OF POLYETHYLENES, AFTER APSE[8]

Type of Polyethylene		Nominal Density (g/cc)
[O		under 0.910]
I	Low Density (LDPE and LLDPE)	0.910 - 0.925
II	Medium Density	0.926 - 0.940
III	High Density (Copolymer)	0.941 - 0.959
IV	High Density (Homopolymer)	0.960 and higher

The descriptions in parentheses are not part of the ASTM standard and Type O is merely a suggestion for a future class. Except for the inclusion of LDPE with its long branches within Type I, these polymers are all linear polyethylenes.

Most of the polyethylene resins used for the fabrication of FML's for waste containment applications are in the density range of 0.932 - 0.940 g/cm^3 which places the material in the upper range of the medium density category, not the customarily referenced high density, or HDPE, category as defined by ASTM D-1248. The addition of carbon black, however, will bring the final compound to a gross density range of 0.941 g/cm^3, or greater, which the liner industry then refers to as HDPE. In this standard-of-practice we will also refer to the material as HDPE thereby recognizing that the above stated industry position is the customarily accepted situation.

4. AN OVERVIEW OF POLYETHYLENE SEAMING METHODS

Due to the high chemical resistance of most polyethylenes, they cannot be solvent bonded like other thermoplastic FMLs. Furthermore, their surface hardness prevents taping as with thermoset FMLs. Thus polyethylenes are either *extrusion welded or thermal fused (melt bonded) for seam fabrication.* Both categories have a number of specific techniques.[10]

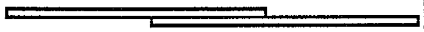
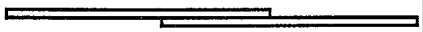
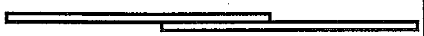
Extrusion welding is used exclusively on FMLs made from polyethylene. It is a direct parallel of metallurgical welding in that a ribbon of molten polymer is extruded over the edge of, or in between, the two surfaces to be joined. The hot extrudate causes the surfaces of the sheet material to become molten and the entire mass then fuses together. One particular system has a mixer in the molten zone which aids in homogenizing the extrudate and the molten surfaces. The technique is called *extrusion fillet welding* when the extrudate is placed over the leading edge of the seam, and is called *extrusion flat welding* when the extrudate is placed between the two sheets to be joined. It should be noted that extrusion fillet welding is essentially the only method that can be used for patching and in poorly accessible areas like sump bottoms and around pipes.

There are a number of thermal fusion or melt bonding. methods that can be used on semicrystalline geomembrane materials like polyethylene. In all of them, portions of the opposing geomembrane surfaces are truly melted. This being the case, temperature, pressure and seaming rate all play important roles in that too much melting weakens the geomembrane and too little melting results in poor seam strength. *Hot air* makes use of a device consisting of a resistance heater, a blower, and temperature controls to blow air between two sheets to melt the opposing surfaces. Usually, temperatures of the "gun" greater than 480°F (250°C) are required. Immediately following the melting of the surfaces, pressure is applied by counter-rotating knurled rollers on the top and bottom of the seamed area. The hot air technique is not recommended to be used as a permanent seaming method for polyethylene FMLs and will not be discussed as a major topic. It is, however, used to tack sheets together for subsequent (permanent) seaming. In this case, a hand held hot air heater is generally used. The *hot wedge* or *hot shoe* method consists of an electrically heated resistance element in the shape of a wedge that is passed between the two sheets to be sealed. As it melts the surfaces, a shear flow occurs across the upper and lower surfaces of the wedge and then roller pressure is applied. Hot wedge units are automated as far as temperature, amount of pressure applied and travel rate is concerned. A single hot wedge is continuous in its width, while a dual hot wedge (or "split" wedge) forms two parallel seams with an unbonded space between them. This space is subsequently pressurized with air for seam continuity testing. *Dielectric* bonding is used only for factory seams and not for HDPE. It is regularly used for other FML materials including some lower density polyethylenes. An alternating current is used at a frequency of approximately 27 MHz, which excites the polymer molecules, generating heat by intermolecular friction. This melts the polymer and when followed by roller pressure a seam results. A variation of this method has recently been introduced for the manufacture of field seams on some types of the lower density polyethylene liners, but not HDPE. The method will not be further described in this manual. *Ultrasonic* bonding utilizes a wedge shaped tool, or "horn", vibrating at approximately 40 kHz which is passed between the overlapped FML sheets in a manner similar to a hot wedge. The vibration of a knurled portion of the tip of the wedge creates heating of the FML by friction into a molten state. Pressure is then applied to squeeze the sheets together via a set of opposing wheels which follows the melting process. The method is in the development stage and has only recently been used in the field for HDPE liners. It will not be further described in this manual. *Electric resistance welding* is yet another new technique for polyethylene seaming wherein a stainless steel wire is placed between overlapping geomembranes and energized with approximately 36 volts and 10 to 25 amps current. The hot wire radially melts the entire region within about 60 seconds to develop a bond. It is later used with a high voltage and a low current in it and a questioning wire outside of the seamed region thereby becoming a nondestructive testing method for locating pinholes. Since this method is also in a development stage, it will not be further described in this manual.

The above mentioned seaming techniques for polyethylene have recently been reviewed(11), see Table 3, which illustrates the seam configuration and many relevant comments. It should be fully recognized that the seaming of thick sheets of polyethylene is a formidable task which requires considerable care and expertise. In the text to follow the three most common seaming methods will be specifically addressed in as much detail as possible. Such details are at the heart of proper field seaming of polyethylene FML's. The specific methods to be described are the following:

- extrusion fillet seams
- extrusion flat seams
- hot wedge (or hot shoe) seams

TABLE 3. VARIOUS SEAMING METHODS FOR POLYETHYLENE FMLS (modified from reference #11)

Method	Seam Configuration	Typical Rate	Comments
Extrusion Fillet*		200 ft/hr.	Upper and lower sheets must be ground Upper sheet must be beveled for 50 mil and greater Height and location are hand controlled Can be rod or pellet fed Extrudate must use same polymer compound Air heater can preheat sheet Routinely used for difficult details
Extrusion Flat*		300 ft/hr.	Upper and lower sheets must be ground Good on long flat surfaces Highly automated and patented machine Cannot be used for close details Extrudate must use same polymer compound Air heater can preheat sheet Controlled pressure and temperature
Hot Air		50 ft/hr.	Good to tack sheets together Hand held and automated devices Air temperature fluctuates greatly No extrudate added
Hot Wedge* (a) Single Track (b) Dual Track	 	300 ft/hr. 300 ft/hr.	Single and double tracks available Double track may be patented Built-in nondestructive test Cannot be used for close details Highly automated machine No extrudate added Controlled pressure for squeeze-out
Dielectric		unknown	Only for factory seams Cannot be used for close details No extrudate added
Ultrasonic		unknown	New technique for FMLs Sparse experience in the field Capable of full automation No extrudate added
Electric Resistance Welding		unknown	New technique for FMLs Still in development stage No extrudate added Wire coating must use same polymer compound Wires provide possibility of doing spark test

*Methods described in this manual

5. DETAILS OF EXTRUSION FILLET SEAMS

5.1 FML Preparation

(a) Note, that this document assumes that the proper FML has been delivered to the site and has been brought to its exact plan position for final installation and seaming.

(b) The two FMLs to be joined must be properly positioned such that a minimum of 4 in. of overlap exists.

(c) If the overlap is insufficient, lift the FML up to allow air beneath it and "float" it into proper position. Avoid dragging FML sheets particularly when they are on rough soil subgrades since scratches in the material can create various stress points of different depths and orientations.

(d) If the overlap is excessive and is to be removed it should be done by trimming the lower sheet only. If this is not possible and the upper sheet must be trimmed do not use a knife with an unshielded blade to cut off the excessive amount because the blade facing downward can easily scratch the underlying FML in a very vulnerable location. A shielded blade or a hook blade should be used to trim off the excess FML. A photograph of such a device is shown in Figure 2. Whenever possible it should be used from beneath the liner in an upward cutting motion.

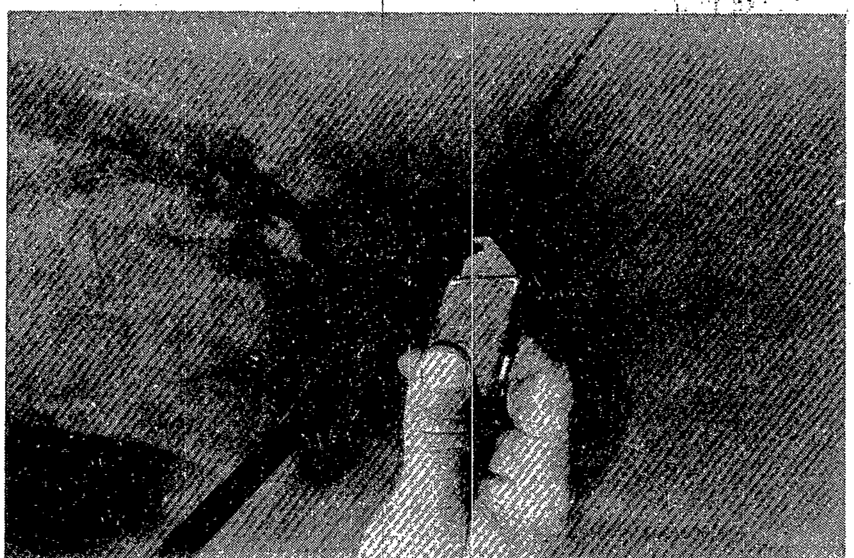


Figure 2. Type of Hook Blade Used for the Cutting of Liner Materials

(e) All cutting and preparation of odd shaped sections or small fitted pieces must be completed at least 50 ft ahead of the seaming operation so that seaming may be continued with as few interruptions as possible.

(f) Check the two opposing FMLs to be joined for acceptability as far as lack of scratches, blemishes, flaws, color, texture and other visual characteristics are concerned.

(g) If the plans require overlaps to be shingled in a particular direction this should be checked.

(h) Excessive undulations (waves) along the seams during the seaming operations should be avoided. When this occurs due to either the upper or lower sheet having more slack than the other, it often leads to the undesirable formation of "fishmouths" which must be trimmed, laid flat and reseamed via a patch.

(i) There generally will be designed-in slack that may appear to be excessive in the FML's depending on the ambient temperature, length of time the FML will be exposed, location in the facility, etc. This is a design consideration and the plans and specifications must be project specific on the amount and orientation of slack.

(j) The sheets which are overlapped for seaming must be clean. If dirty, they must be wiped clean with dry rags.

(k) The sheets which are overlapped for seaming must be completely free of moisture in the area of the seam. Air blowers are usually preferred over rags because sufficient dry rags are usually not available to keep the FML dry enough to be suitable for seaming.

(l) Seaming is not allowed during rain or snow, unless proper precautions are made to allow the seam to be made on dry FML materials, e.g., within an enclosure or shelter.

(m) The soil surface beneath the FMLs cannot be saturated, because the heat of seaming will attract water to the region to be joined. Ponded water on the soil's surface beneath the FML is never allowed.

(n) If the soil beneath the FML is frozen, the heat of seaming can thaw the frost allowing water to be attracted to the region to be joined. This is not acceptable and must be avoided.

(o) Ambient temperatures for seaming should be above freezing, i.e. 32°F (0°C) unless it can be proven via test strips that good seams can be fabricated at lower temperatures. However, temperature (per se) is less a concern to good seam quality than is moisture.

(p) For cold weather seaming, it may be advisable to preheat the sheets with a hot air blower, to use a tent of some sort to prevent heat losses during seaming and to make numerous test welds in order to determine appropriate seaming conditions, e.g., equipment temperatures may have to be set higher and seaming rates slowed down during cold weather seaming.

(q) Ambient temperatures for seaming should be below 105°F (40.6°C) measured two feet above the liner at which point the FML is significantly warmer and working conditions become extremely difficult.

5.2 Equipment Preparation

(a) A working and properly functioning small electric generator must be available within close proximity of the seaming region and with adequate extension cords to complete the entire seam. The generator must be rubber tired, or placed on a smooth plate such that it is completely stable so that no damage can occur to the FML or to the clay liner. Fuel (gasoline or diesel) for the generator must be stored off of the FML.

(b) A hand-held electric rotary grinder having a circular disk grinding plate approximately 4.0 in. in diameter and adequate #80 grit paper must be available. See the photograph of Figure 3 following. Also acceptable is #100 grit paper which is finer than #80. Sandpaper coarser than #80, e.g. #60, is not acceptable.

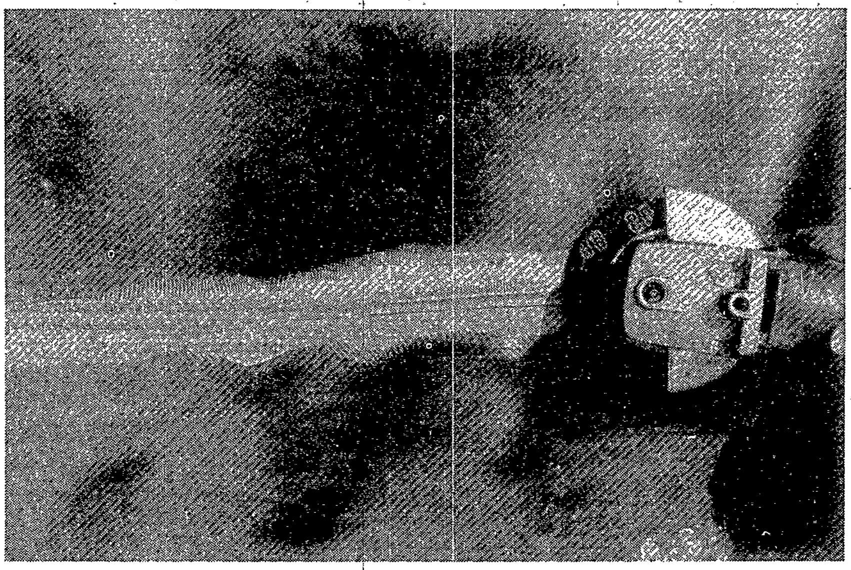


Figure 3. Hand-Held Electric Rotary Grinder with Circular Disc Grit Grinding Paper

(c) A hot air welder or hot wedge with temperature capability to 480°F (250°C) must be available to tack weld the FML sheets after they are properly positioned.

(d) The extrusion fillet welding apparatus may be of two types depending upon the location where the seams are to be made. Either rubber wheeled, automated seam extruders or hand-held portable extruders are available. Photographs of various systems are shown in Figure 4.

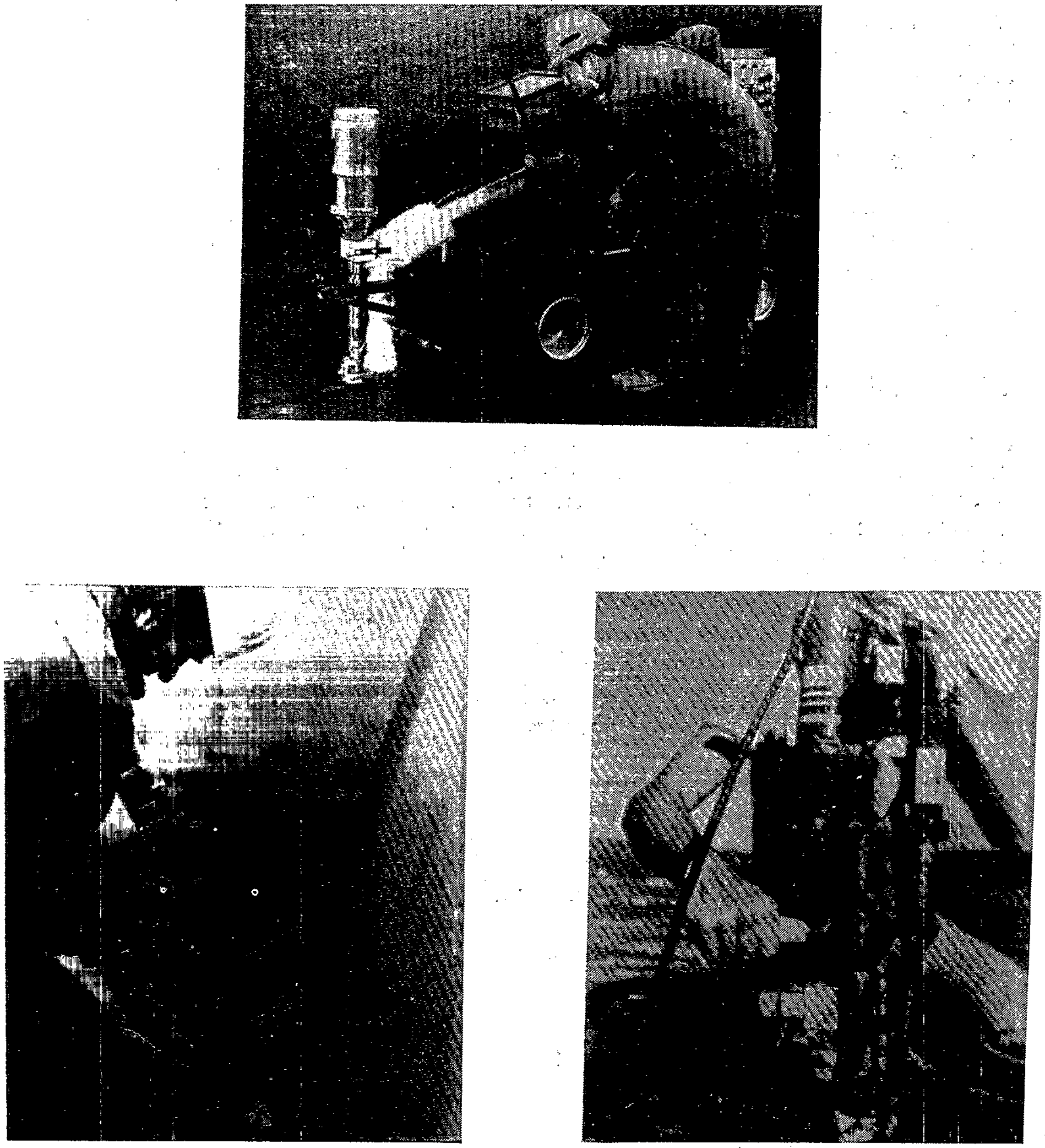


Figure 4. Photographs of Various Types of Extrusion Fillet Welding Devices
Upper: Automated Type
Lower: Hand Held Type

(e) All extrusion fillet seaming devices must be equipped with properly functioning temperature controllers displaying the temperature in the extrusion barrel.

(f) All types of extrusion fillet seaming devices have teflon or metal dies of different shapes and sizes where the extrudate exits onto the FML. These dies must be inspected for wear, sharp notches or creases, and for correctness for the particular application. Commercially available extrusion dies are available for 30, 40, 60, 80 and 100 mil sheet thicknesses. Many, however, are specifically made or modified by installers. Both the width and thickness of the extrudate are dependent upon the proper die. It must be field verified for correctness, a detail which will be described later.

(g) Adequate extrudate welding rod or pellets, of exactly the same type as the FML itself, must be available, dry, clean and ready for feeding through the extruder. All extrudate resin must be properly formulated with the same compound as the FML sheet material. If in doubt, chemical fingerprinting methods must be performed.(6) All extrudate material must be kept free of dirt, debris and foreign matter.

5.3 Actual Seaming Process

(a) Whenever the FMLs are 50 mils in thickness or greater, the leading edge of the upper sheet must be ground to a 45° bevel. It is important that the sheet to be beveled is lifted up off of the lower sheet so that no grind marks whatsoever occur in the lower sheet, see Figure 5 following. Note that grinding must be done prior to tack welding in order to exercise control against damage to the lower sheet.

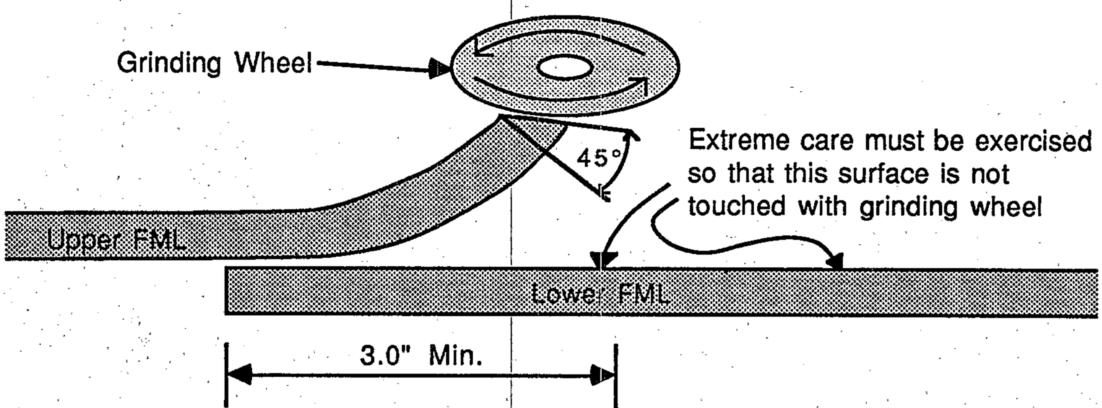


Figure 5. Preparing the Bevel of the Upper FML for Liner Thicknesses Greater Than 50 Mil

(b) Following the preparation of the bevel, the upper sheet is lowered and laid flat on the lower sheet and the horizontal surface grinding of both upper and lower sheets is completed as shown in Figure 6. All of the surface sheen in the area to be seamed must be totally removed. Heavy textured grit sand paper coarser than #80 size that leaves deep ridges that might become stress points or leak channels are unacceptable. All of the material that has been ground from the FML sheets must be wiped or blown away from the actual seaming zone.

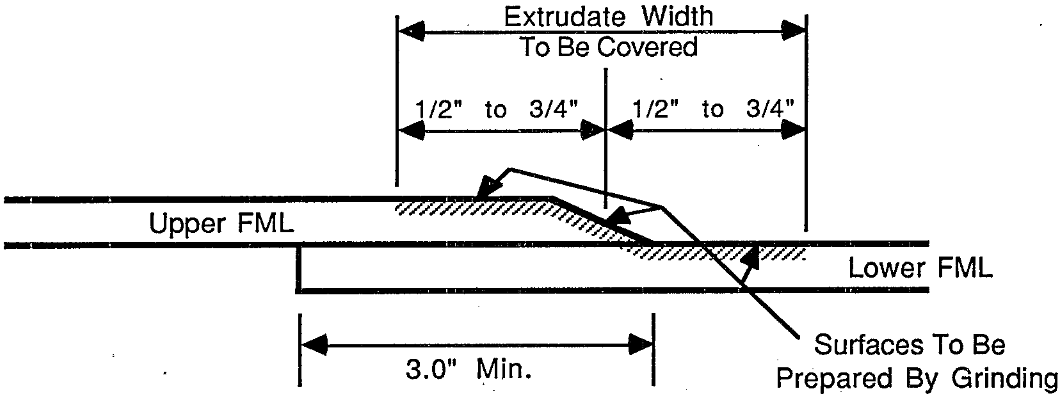


Figure 6. Proper Orientation and Grinding Preparation of Sheets Prior to Tacking and Extrudate Placement

(c) The preferred orientation of grinding marks is *perpendicular* to the seam direction rather than parallel to it. It should be mentioned that this is a slower process for the installation contractor to perform. The reason for parallel grinding is that deep, parallel grooves decrease parent material thickness and can lead to seam failure in the parent material. Although the film tear bond criterion is usually satisfied it is often at a reduced stress due to the thinner material. Additionally, parallel grinding marks can give rise to stress crack initiation. See Figure 7 following for the distinction between the two different patterns. Please note that both grinding patterns are excessive in their extent beyond the extrudate and are shown for illustration purposes only.

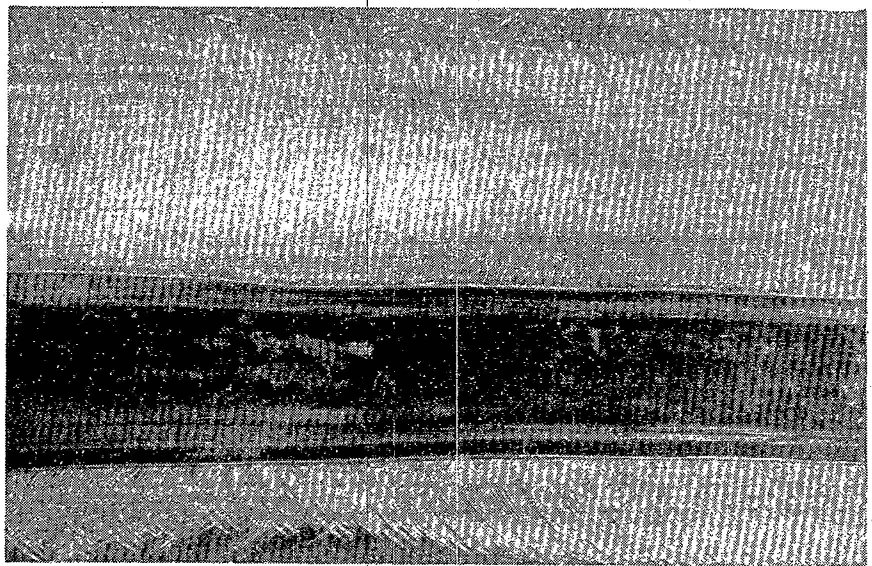
(d) The depth of the grinding marks (whatever the direction) is of paramount interest. Grind marks should never be more than 10% of the sheet thickness and in general should only be approximately 5% of the sheet thickness. The objective of grinding is to remove oxide layers and waxes from the surfaces and to roughen the sheets.

(e) Regarding the extent of the grinding, the general rule should be that grinding marks should not appear beyond 1/4 inch of the extrudate after it is placed, see Figure 8. Thus if the final extrudate bead width is 1.5 in. width, the total grinding pattern should be no more than 2.0 in., which is one inch on each side of the weld centerline.

(f) Grinding shall be completed no more than 10 minutes before seaming takes place so that surface oxide layers are not recreated prior to placement of the extrudate.

(g) The hand held grinder used for the grinding process must be turned off whenever it is not in use. Never leave it running. If it contacts the liner while running it will cause serious damage.

(h) A hot air or hot wedge welder may be used to "tack" the two sheets together thereby maintaining proper alignment and intimate contact between the two sheets. The tacking should be just that, it is not meant to be the primary seam. There should be no heat distortion showing on the surface of the upper sheet. Note that if the tacking is done before the beveling and grinding operations described in steps "a" through "g", then extreme caution against overgrinding and mistakes must be taken. It might be



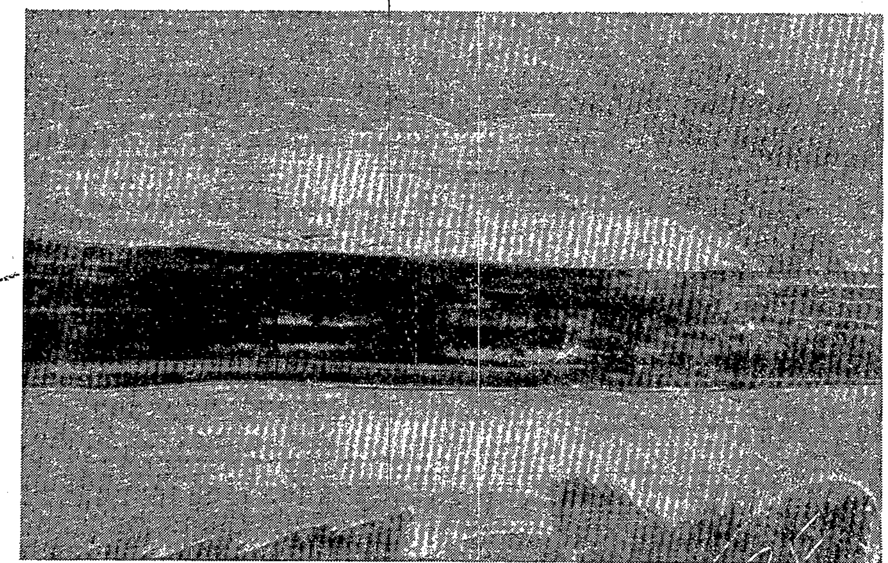


Figure 7. Photographs of Different Orientations of Grinding Patterns
Upper: Grind Marks Perpendicular to Seam (Recommended Pattern)
Lower: Grind Marks Parallel to Seam (Not Recommended Pattern)
(Note, however, that both situations have grinding far in excess of what is required and are shown for illustration of the grinding patterns only, see Figure 8 following)

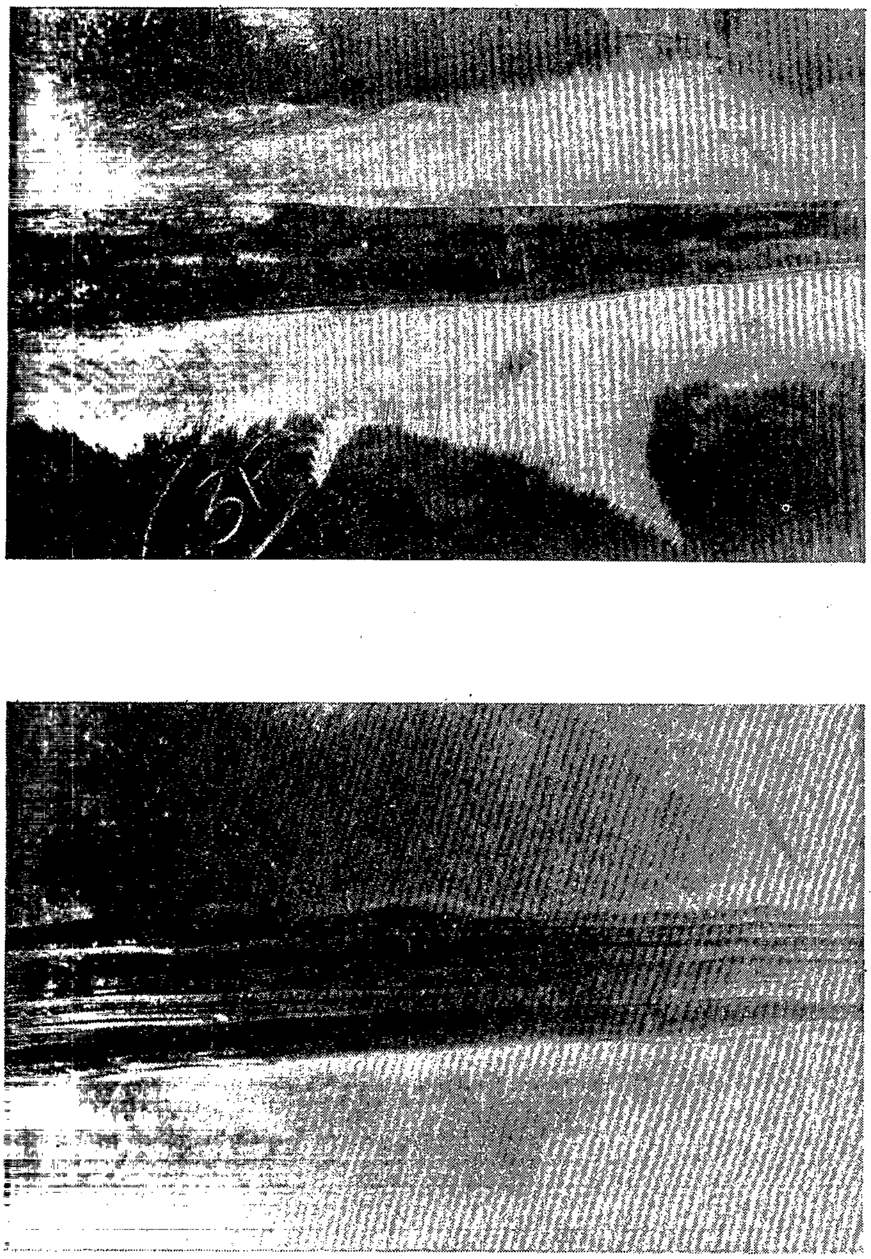


Figure 8. Photographs of Different Extent of Grinding Patterns After Extrusion Fillet Seaming
Upper: Excessive and Irregular Grinding Beyond Extrudate
Lower: Acceptable Grinding Pattern Just Showing Beyond Extrudate

necessary to provide a wedge to lift up the overlying FML as shown in Figure 9 or to use a thin metal sheet with rounded corners and slide it along the grinding area on top of the bottom sheet. Double sided tape should not be used, as it includes trace levels of hydrocarbon solvents that may be released and affect environmental monitoring.

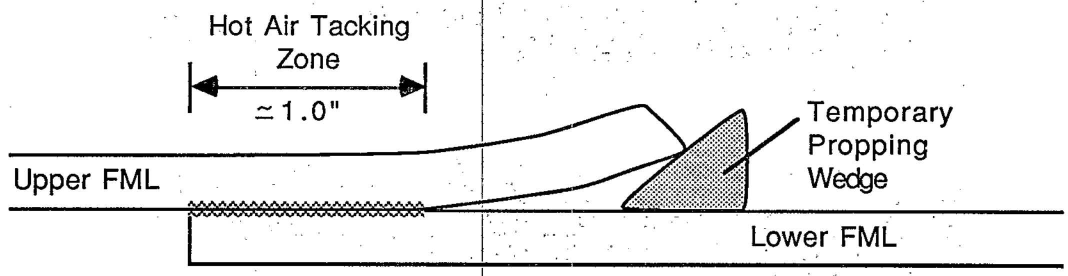


Figure 9. Smooth Propping Wedge Used When Tacking of Sheets is Done Before Surface Grinding of the FML Sheets

(i) The extrusion welder is to be purged of all heat degraded extrudate in the barrel prior to beginning a seam. This must be done every time the extruder is restarted after a 2 min., or longer, down time. The purged extrudate should not be discharged onto the surface of previously placed liner nor on the prepared subgrade where it would eventually form a hard lump under the liner.

(j) Extrudate in the form of a molten, viscous bead is now deposited over the overlapped seam. The center of the extrudate must be directly over the edge of the upper FML. The extrudate should cover the grind marks on each side of the upper FML to within 1/4 in. Note the photographs following this section for proper extrudate placement.

(k) The extrudate thickness should be approximately two times the specified sheet thickness measured from the top of the bottom sheet to the top or crown of the extrudate, see Figure 10. Excessive squeeze-out (or flashing) as shown in the lower sketch of Figure 10 is acceptable as long as it is equal on both sides and will not interfere with subsequent vacuum box testing. If, however, pulling up on the extrudate squeeze-out pulls the entire extrudate off of the sheet it is obviously unacceptable. Squeeze-out generally means that the extrusion die was not riding directly against the FML, the extrudate temperature was improper for adequate flow, or the seaming rate was too slow.

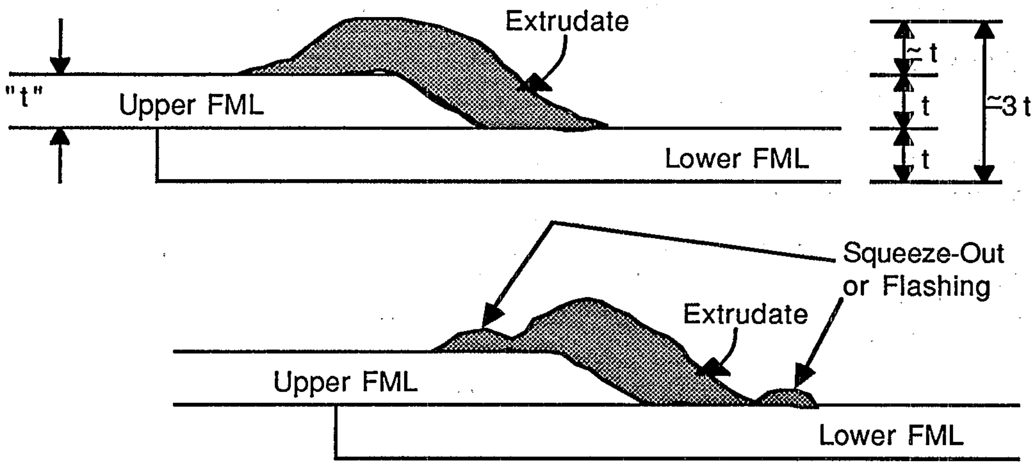


Figure 10. Schematic Diagrams of Various Cross Sections of Fillet Extrusion Seams

(l) Where possible, inspect the underside of the lower FML for heat distortion. This can be done at the end of seams and where samples are cut out of the seam. A slight amount of thermal "puckering" on relatively thin FMLs (for example, less than 50 mils) is acceptable. It signifies that heat was felt through the entire sheet. If the underside is greatly distorted, however, lower the temperature or increase the rate of seaming. For thick FMLs of 80 mils or greater there should never be any indication of this type of thermal "puckering".

(m) Depending upon the records to be kept, one might record a number of different temperatures. For example, the temperatures of the extruding apparatus' melt zone, the extrudate temperature at the nozzle, the FML surface temperature and the ambient temperature. This is a site specific decision.

5.4 After Seaming

(a) A smooth insulating plate or heat insulating fabric is always to be placed beneath the hot extrusion welding apparatus after usage. The tip die and barrel must not be placed on any FML or other geosynthetic surface -- it is *extremely* hot and can cause severe damage.

(b) Visual inspection of the extrudate bead should be made particularly for straight line alignment, height, and uniformity of surface texture. There should be no bubbles or pock marks in the extrudate. Such surface details on the extrudate indicates the presence of air, water or debris within the extrudate rod or pelletized polymer.

(c) Grind marks should only be visible for 1/4 in. beyond the extrudate. They should be extremely faint and never appear as heavy gouge marks, recall the earlier photographs. Excessive grinding also has a depth consideration. As stated previously, excessive is considered to be greater than 10% of the FML thickness. If it is excessive, do not apply additional extrudate over the original extrusion fillet seam. It is necessary to place a cap strip over the entire seam where the excessive grinding is observed.

(d) If properly planned, each seam run should terminate at a panel end, at a specific detail or on a long straight run where it can be easily resumed.

(e) If the seaming needs to be interrupted at mid-seam, the extrudate end should trail off gradually, rather than terminate with a large mass of solidified extrudate.

(f) Where extrusion fillet welds are temporarily terminated long enough to cool, they must be ground prior to applying new extrudate over the existing seam. This restart procedure must necessarily be followed on patches, pipes, fittings, appurtenances and "T" or "Y" seams.

(g) Photographs of various types of extrusion fillet seams follow in Figure 11.

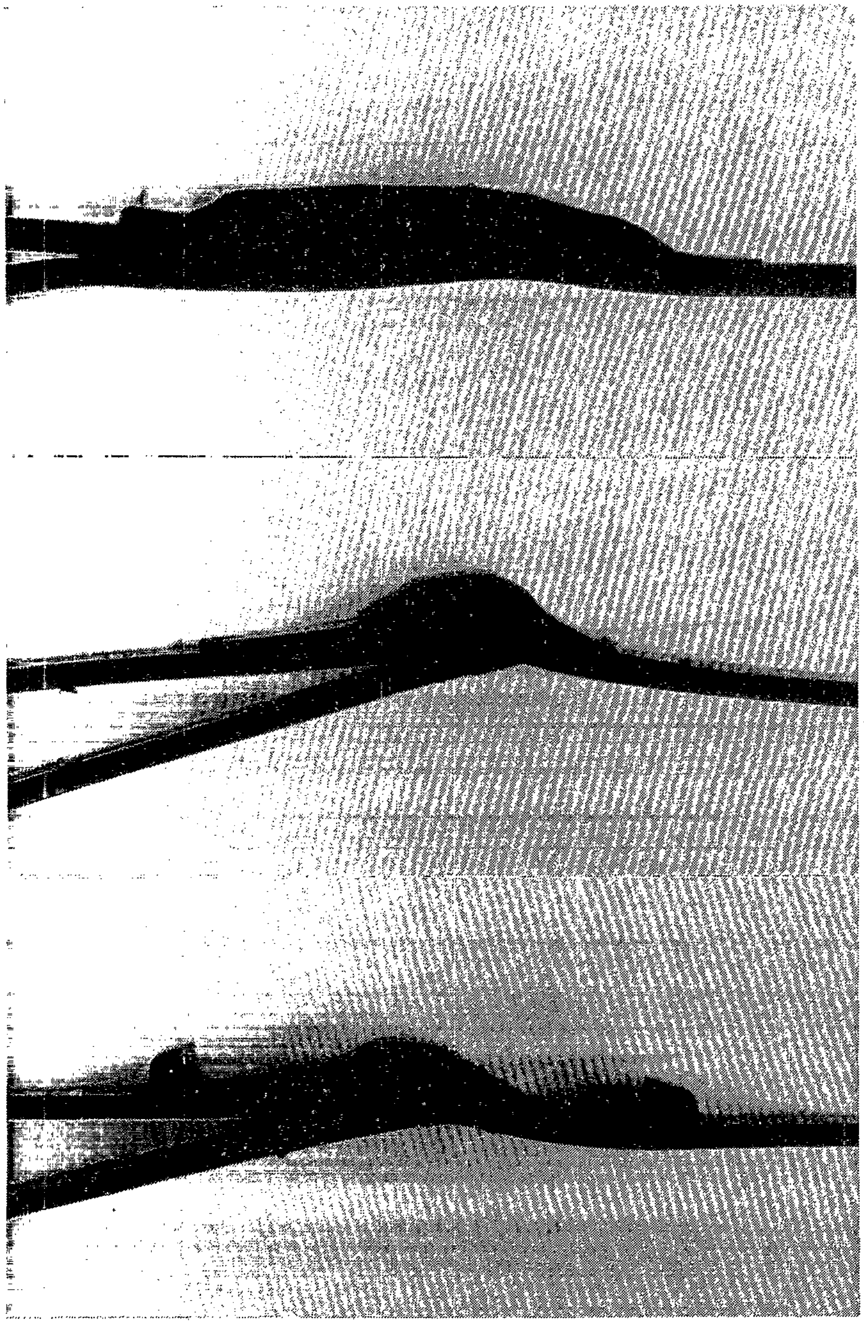


Figure 11. Photographs of Cross Sections of Various Types of Extrusion Fillet Seams
Upper: Machine Extrusion Seam without Squeeze-Out
Middle: Hand Held Extrusion Seam without Squeeze-Out (note thermal puckering at bottom at seam)
Lower: Hand-Held Extrusion Seam with Squeeze-Out

6. DETAILS OF EXTRUSION FLAT SEAMS

6.1 FML Preparation

(a) Note, that this document assumes that the proper FML has been delivered to the site and has been brought to its exact plan position for final installation and seaming.

(b) The two FMLs to be joined must be properly positioned such that a minimum of 4 in. of overlap exists.

(c) If the overlap is insufficient, lift the FML up to allow air beneath it and "float" it into proper position. Avoid dragging FML sheets particularly when they are on rough soil subgrades since scratches in the material can create various stress points of different depths and orientations.

(d) If the overlap is excessive and is to be removed it should be done by trimming the lower sheet only. If this is not possible and the upper sheet must be trimmed do not use a knife with an unshielded blade to cut off the excessive amount because the blade facing downward can easily scratch the underlying FML in a very vulnerable location. A shielded blade or a hook blade should be used to trim off the excess FML. A photograph of such a device is shown in Figure 12. Whenever possible it should be used from beneath the liner in an upward cutting motion.

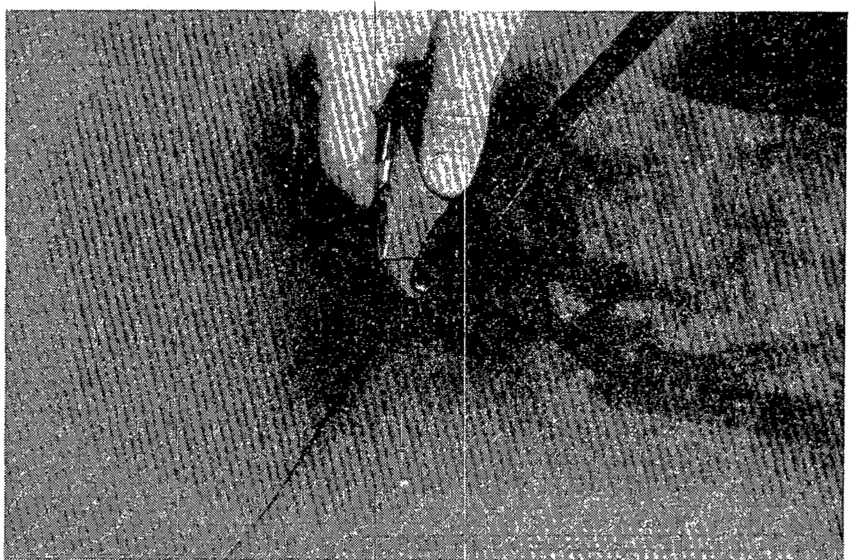


Figure 12. Type of Hook Blade Used in the Cutting of Liner Materials

(e) All cutting and preparation of odd shaped sections or small fitted pieces must be completed at least 50 ft ahead of the seaming operation so that seaming may be continued with as few interruptions as possible.

(f) Check the two opposing FMLs to be joined for acceptability as far as lack of scratches, blemishes, flaws, color, texture and other visual characteristics are concerned.

(g) If the plans require overlaps to be shingled in a particular direction this should be checked.

(h) Excessive undulations (waves) along the seams during the seaming operation should be avoided. When this occurs due to either the upper or lower sheet having more slack than the other, it often leads to the undesirable formation of "fishmouths" which must be trimmed, laid flat and reseamed via a patch.

(i) There generally will be excessive slack in the FML's depending on the ambient temperature, length of time the FML will be exposed, location in the facility, etc. This is a design consideration and the plans and specifications must be project specific on the amount and orientation of slack.

(j) The sheets which are overlapped for seaming must be clean. If dirty, they must be wiped clean with dry rags.

(k) The sheets which are overlapped for seaming must be completely free of moisture in the area of the seam. Air blowers are usually preferred over rags because sufficient dry rags are usually not available to keep the FML dry enough to be suitable for seaming.

(l) Seaming is not allowed during rain or snow, unless proper precautions are made to allow the seam to be made on dry FML materials, e.g., within an enclosure or shelter.

(m) The soil surface beneath the FMLs cannot be saturated, because the heat of seaming will draw the water into the region to be joined. Ponded water on the soil's surface beneath the FML is never allowed.

(n) If the soil beneath the FML is frozen, the heat of seaming can thaw the frost allowing water to be drawn into the region to be joined. This is not acceptable and must be avoided.

(o) Ambient temperatures for seaming should be above freezing, i.e. 32°F (0°C) unless it can be proven via test strips that good seams can be fabricated at lower temperatures. However, temperature (per se) is less a concern to good seam quality than is moisture.

(p) For cold weather seaming, it may be advisable to preheat the sheets with a hot air blower, to use a tent of some sort to prevent heat losses during seaming and to make numerous test welds in order to determine appropriate seaming conditions, e.g., equipment temperatures may have to be set higher and seaming rates slowed down during cold weather seaming.

(q) Ambient temperatures for seaming should be below 105°F (40.6°C) measured two feet above the liner at which point the FML is significantly warmer and working conditions become extremely difficult.

6.2 Equipment Preparation

(a) A working and properly functioning small electric generator must be available within close proximity of the seaming region and with adequate extension cords to complete the entire seam. The generator must be rubber tired, or placed on a smooth plate such that it is completely stable so that no damage can occur to the FML or to the clay liner. Fuel (gasoline or diesel) for the generator must be stored off of the FML.

(b) Grinding of the opposing FML surfaces to be joined is to be done with a hand held rotary grinder having #80 disk sandpaper. Finer paper's, e.g. #100, are allowable, but not coarser.

(c) The grinding of the lower sheet is to be done first, with a suitable width (approximately 2 to 3 inches) being prepared such that surface oxide is removed and the sheet is roughened. The depth of the grind marks must be no greater than 10% of the original thickness of the sheet.

(d) The upper sheet is bent over backwards so that its underside can be ground at the location where it will meet the lower sheet's prepared surface. It is important to note that all ground sheet must eventually be covered with extrudate to within 1/4 in.

(e) Alternatively to the type of surface preparation just described in parts "b", "c", and "d", an automated wire brush technique can be used. With this instrument it is possible to prepare the bottom of the top sheet and the top of the bottom sheet at the same time. See Figure 13.

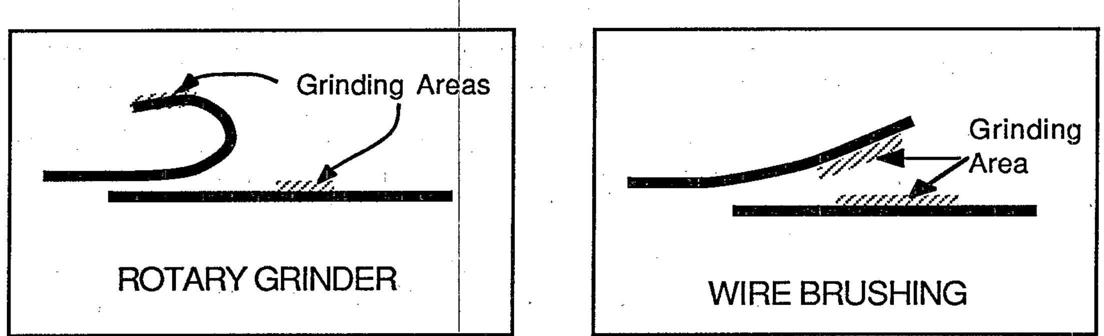
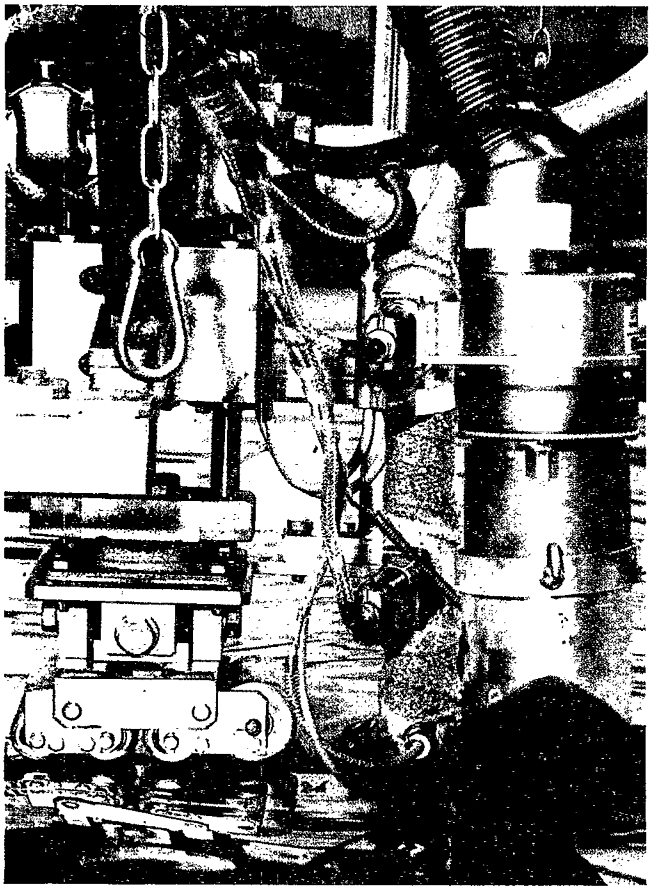


Figure 13. Grinding Locations and Method Used in the Preparation of Flat Extrusion Seams

(f) The extruder itself must be purged of old extrudate. This extrudate should not be ejected on the previously placed FML nor on the soil subgrade where it will form a hard lump beneath the liner.

(g) Some extrudate should also be ejected to see if the nozzle is the appropriate width and thickness. Usually flat extrudate ribbons are 1.5 in. to 2.0 in. width and about 60 mils thick. However, welding speed will affect this thickness, which ranges from about 20 mils thick when fast, to 80 mils thick when slow. Properly functioning temperature controllers must monitor the extrudate temperature. A photograph and schematic diagram of a extrusion flat seaming device is given in Figure 14.



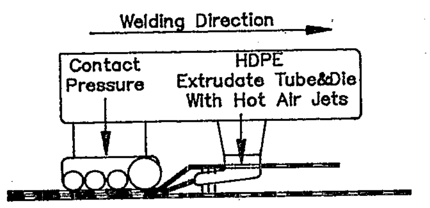


Figure 14. Photograph and Schematic Diagram of Flat Extrusion Seaming of FML Sheets

(h) Preheating of the opposing surfaces to be joined is done by air jet which must be full seam width at a constant temperature. The nozzle should be inspected for obstructions on a daily basis. The actual temperature of the extrudate varies with ambient conditions but is approximately 480°F (250°C). This temperature causes surface softening. Due to the rate of travel, however, the sheet interior is not fully melted.

(i) Pressure rollers should be inspected for sharp edges or irregular surfaces. On some systems these rollers are in tandem where the front set (nearest the extrudate) should be set at a lower pressure than the rear set.

6.3 Actual Seaming Process

(a) The preheat system previously described serves the purpose of preparing the previously ground surfaces to accept the extrudate in the form of a ribbon.

(b) The extrudate is placed at about 480°F (250°C) in a full width, full thickness ribbon, see Figure 15. It cannot be visually inspected since it is occurring between the two sheets, directly following the hot air preparation and directly preceding the pressure rollers.

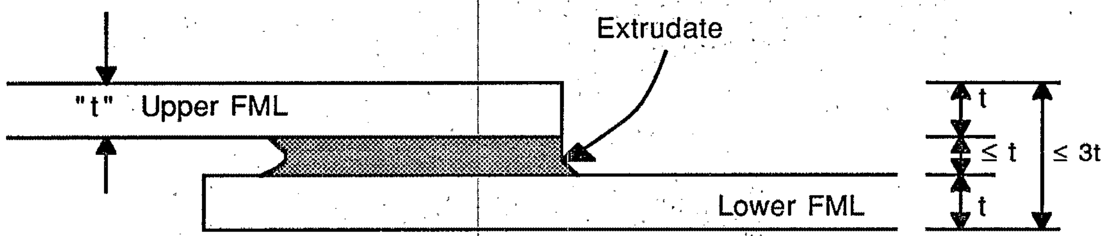


Figure 15. Schematic Diagram of Cross Section of Extrusion Flat Seam with Extrudate Out to the Edge of the Upper FML

(c) The outside edge of the seam should be visually observed to ensure that the extrudate is embedded between the liner sheets. As will be seen in the photographs following this section, three cases are possible. These are the edge of the extrudate being somewhat under the overlapping sheet, exactly even with it, or beyond it in the form of "squeeze-out". Either one of the latter two situations are necessary if vacuum box testing of the seam is subsequently required.

(d) The rollers exert considerable pressure and are adjusted according to sheet thickness. Indentations on the surface of the upper FML should be observable but should not create a rut, e.g., the indentation should be barely capable of being felt.

(e) Thermal "puckering" of the upper surface of the overlying FML should not appear. Although the lower surface of the underlying FML is rarely seen (except at sheet ends, trial strips, or where samples are taken) it should not be puckered. Thermal puckering signifies excessive heat and/or insufficient seaming rate.

(f) Depending upon the records to be kept, one might record a number of different temperatures. For example, the temperatures of the extruding apparatus melt zone, the extrudate temperature at the nozzle, the FML surface temperature, and the ambient temperature. This is a site specific decision.

6.4 After Seaming

(a) Hand held grinders or mechanical wire brushes are *always* to be turned off when not in use. If placed on the FML while running they can cause considerable damage.

(b) A smooth insulating plate or heat insulating fabric is to be placed beneath any hot welding apparatus after usage.

(c) Grinding marks on the lower sheet of the completed seam should be observable but only for a distance of 1/4 in. beyond the extrudate. Note, however, that only the lower sheet can be inspected in this regard.

(d) Placement of the extrudate to the edge of the upper sheet or squeeze-out of the extrudate beyond the edge is necessary if vacuum box testing is required.

(e) If properly planned, each seam run should terminate at a panel end, specific detail or on a long straight run where it can be easily resumed.

(f) Where extrusion flat welds are terminated long enough to cool, the start-up continuation seam must completely melt the leading edge of the cooled seam. Since this is occurring beneath the overlapped sheet and cannot be observed, the location must be marked for subsequent vacuum box testing. If it fails, a cap strip must be placed over the general area.

(g) The extrudate end should trail off gradually, rather than terminate with a large mass of solidified extrudate.

(h) Photographs of the various types of extrusion flat seams are shown in Figure 16.

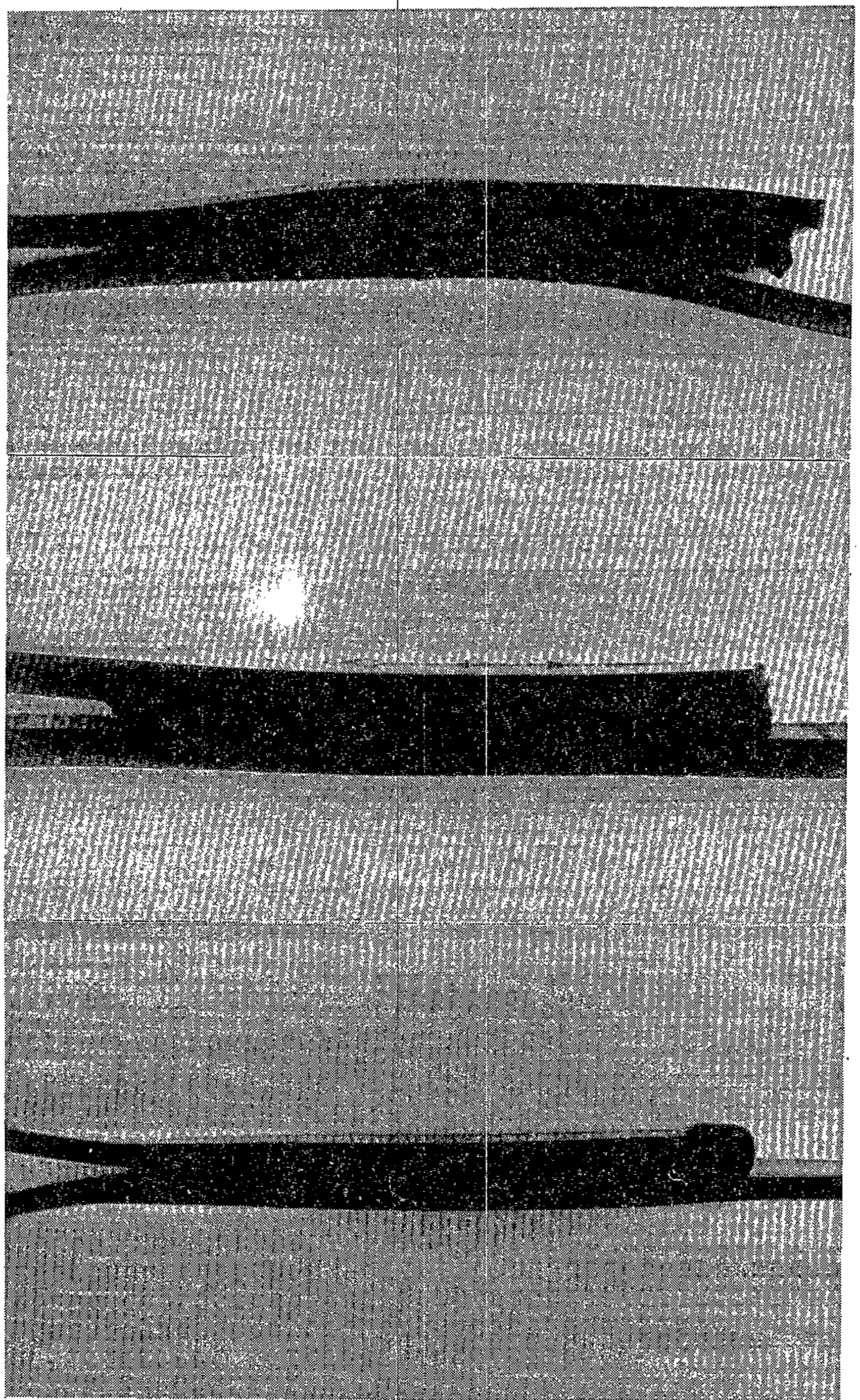


Figure 16. Photographs of Cross Sections of Extrusion Flat Seams
Upper: Extrudate Short of the Edge of Overlapping Sheet
Middle: Extrudate Exactly at the Edge of Overlapping Sheet
Lower: Extrudate Squeeze-Out Beyond the Edge of Overlapping Sheet

7. DETAILS OF HOT WEDGE SEAMS

7.1 FML Preparation

(a) Note, that this document assumes that the proper FML has been delivered to the site and has been brought to its exact plan position for final installation and seaming.

(b) The two FMLs to be joined must be properly positioned such that typically 3 to 5 in. of overlap exists. The actual value depends on the width of the wedge element to be used.

(c) If the overlap is insufficient and it does not fully cover the wedge, lift the FML up to allow air beneath it and "float" it into proper position. Avoid dragging FML sheets particularly when they are on rough soil subgrades since scratches in the material can create various stress points of different depths and orientations.

(d) If the overlap is excessive and is to be removed it should be done by trimming the lower sheet only. If this is not possible and the upper sheet must be trimmed do not use a knife with an unshielded blade to cut off the excessive amount because the blade facing downward can easily scratch the underlying FML in a very vulnerable location. A shielded blade or a hook blade should be used to trim off the excess FML. A photograph of such a device is shown in Figure 17. Whenever possible it should be used from beneath the liner in an upward cutting motion.

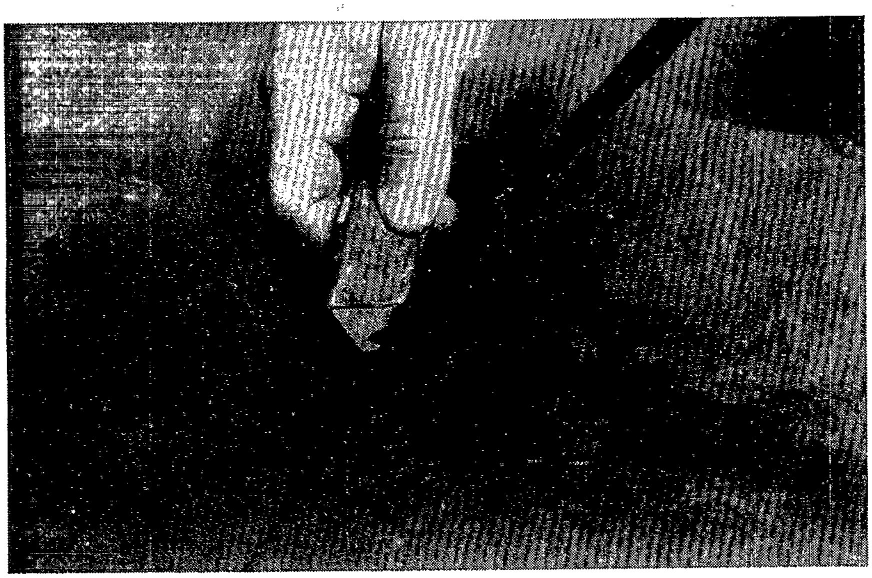


Figure 17. Type of Hook Blade Used in the Cutting of Liner Materials

(e) All cutting and preparation of odd shaped sections or small fitted pieces must be completed at least 50 ft ahead of the seaming operation so that seaming may be continued with as few interruptions as possible.

(f) Check the two opposing FMLs to be joined for acceptability as far as lack of scratches, blemishes, flaws, color, texture and other visual characteristics are concerned.

(g) If the plans require overlaps to be shingled in a particular direction this should be checked.

(h) Excessive undulations (waves) along the seams during the seaming operation should be avoided. When this occurs due to either the upper or lower sheet having more slack than the other, it often leads to the undesirable formation of "fishmouths" which must be trimmed, laid flat and reseamed via a patch.

(i) There generally will be excessive slack in the FML's depending on the ambient temperature, length of time the FML will be exposed, location in the facility, etc. This is a design consideration and the plans and specifications must be project specific on the amount and orientation of slack.

(j) The sheets which are overlapped for seaming must be clean. If dirty, they must be wiped clean with dry rags.

(k) The sheets which are overlapped for seaming must be completely free of moisture in the area of the seam. Air blowers are usually preferred over rags because sufficient dry rags are usually not available to keep the FML dry enough to be suitable for seaming.

(l) Seaming is not allowed during rain or snow, unless proper precautions are made to allow the seam to be made on dry FML materials, e.g., within an enclosure or shelter.

(m) The soil surface beneath the FMLs cannot be saturated, because the heat of seaming will draw the water into the region to be joined. Ponded water on the soil's surface beneath the FML is never allowed.

(n) If the soil beneath the FML is frozen, the heat of seaming can thaw the frost allowing water to be drawn into the region to be joined. This is not acceptable and must be avoided.

(o) Ambient temperatures for seaming should be above freezing, i.e. 32°F (0°C) unless it can be proven via test strips that good seams can be fabricated at lower temperatures. However, temperature (per se) is less a concern to good seam quality than is moisture.

(p) For cold weather seaming, it may be advisable to preheat the sheets with a hot air blower, to use a tent of some sort to prevent heat losses during seaming and to make numerous test welds in order to determine appropriate seaming conditions, e.g., equipment temperatures may have to be set higher and seaming rates slowed down during cold weather seaming.

(q) Ambient temperatures for seaming should be below 105°F (40.6°C) measured two feet above the liner at which point the FML is significantly warmer and working conditions become extremely difficult.

7.2 Equipment Preparation

(a) A working and properly functioning small electric generator must be available within close proximity of the seaming region and with adequate extension cords to complete the entire seam. The generator must be rubber tired, or placed on a smooth plate such that it is completely stable so that no damage can occur to the FML or to the clay liner. Fuel (gasoline or diesel) for the generator must be stored off of the FML.

(b) Hot wedge seaming devices are completely self contained systems sometimes referred to as a "mouse" or "hot shoe". Photographs of different types of hot wedge seaming devices are shown in Figure 18.

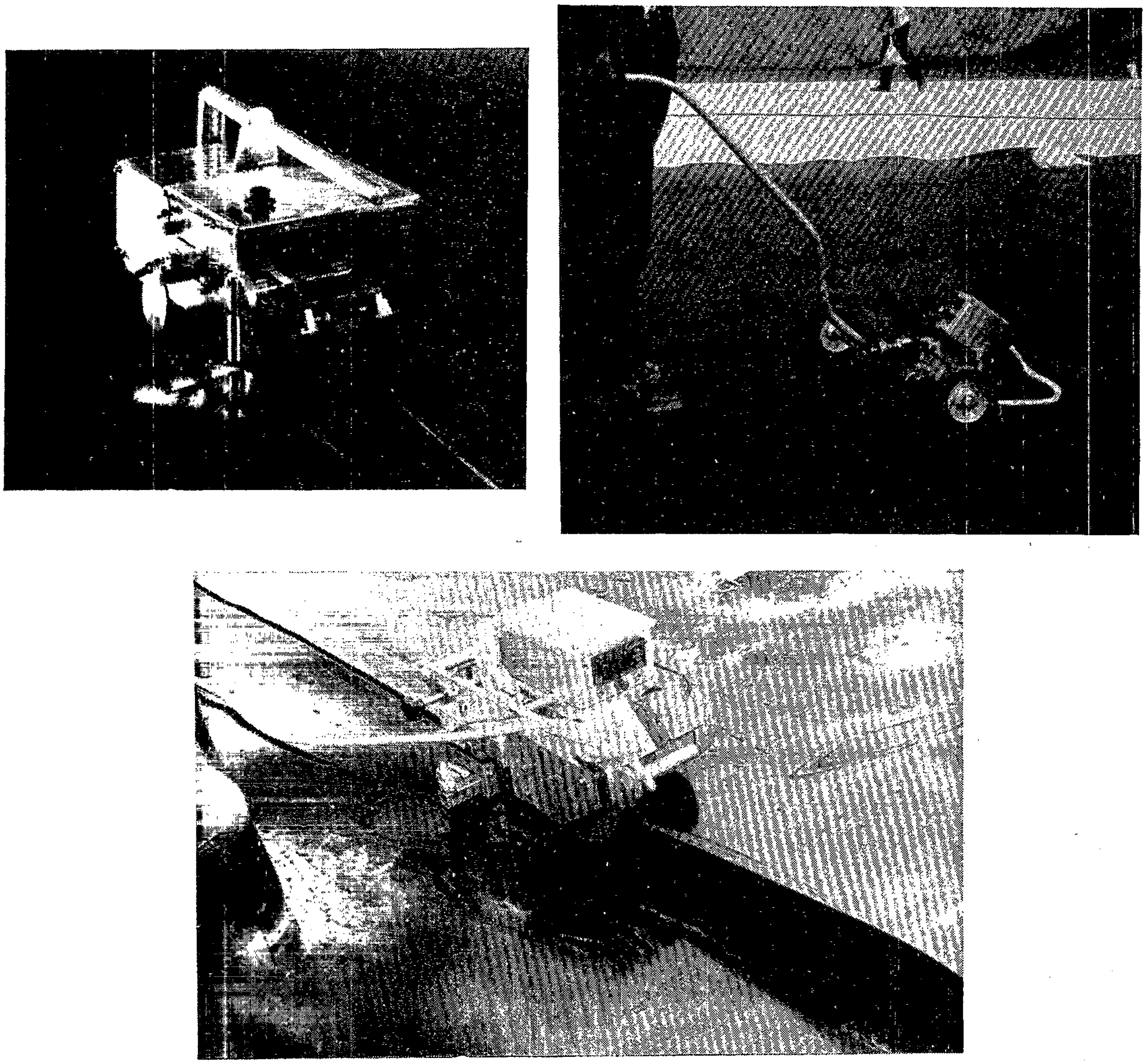


Figure 18. Various Types of Hot Wedge Seaming Devices

(c) As the hot wedge method is one of melting the opposing surfaces of the two FMLs to be joined, no grinding of sheets is necessary, nor allowed.

(d) Tacking of the FML sheets as done in extrusion fillet seaming is not possible since the wedge must travel between opposing parallel sheets which are to be joined.

(e) The hot wedge itself, or "anvil", should be inspected to see that it is uniform and reasonably tapered. Various types are currently available. Some are smooth surfaced while other have patterned ridges in the direction of the seam. The taper dimensions vary according to different types of machines. The major point for inspection is that no sharp edges should exist wherever the FML sheet surfaces must pass.

(f) A single hot wedge has an anvil which is uniform over its entire surface. A dual wedge has a split anvil forming two separate tracks. See the sketches of Figure 10. If a dual, or split, hot wedge seam is being made, the recessed space for the central unseamed portion should be examined.

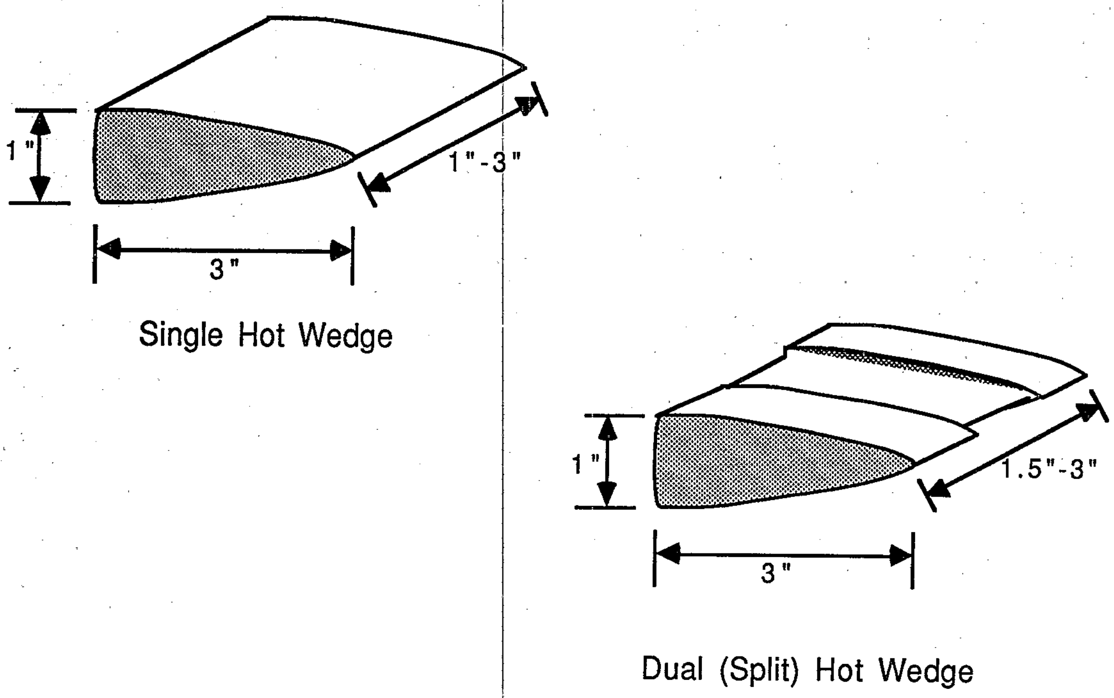


Figure 19. Diagrams of the Hot Wedge Elements (i.e., the Anvil) Upon Which the Two Sheets to be Joined are Passed

(g) When knurled rollers are used for applying pressure on the sheets and driving the device they immediately follow the anvil. They should be inspected for sharp surfaces and for wheels that are not smoothly beveled on the outside (both of which are not allowed).

(h) If a chain drive powers the device and applies pressure to the nip/drive rollers it should be inspected for synchronization of travel and proper functioning.

(i) As the FML sheet materials pass through the machine, they must come in contact with the full width of the wedge in order to heat the material properly. Idler rollers or similar devices, on both sides of the wedge are adjustable and must make the material conform to the wedge as it passes through the machine. These roller heights are adjustable. Adjustment of these devices should be made while the wedge is cold. The procedure for doing this with some equipment is as follows: Insert the lower and upper layers of FML material in the nip/drive rollers, which will change the wedge height between the idler rollers. Then, lock the wedge in position, and adjust the idlers so that one layer fits snugly between the wedge and the idlers. The wedge has an adjustment that is actually a stopping device to keep the wedge from being pulled into the nip/drive rollers. Caution must be taken to ensure that the wedge is not adjusted too closely to the nip/drive rollers, especially when material is not going through the machine. The drive, or wedge units, must be disengaged before the material runs completely out of the machine. Serious damage will occur to the FML sheets if the wedge gets pulled through the nip/drive rollers.

(j) The front part of the seaming device should be inspected for sharp corners and irregular details which may damage the FML's.

(k) Temperature controllers on the wedge device should be set according to thickness, ambient temperature, and rate of seaming. The "test strip" mentioned in the beginning of this manual is essential in this regard. Temperature gages should be checked for accuracy and repeatability.

(l) Force sensors at the nip rollers should be checked for accuracy and repeatability.

7.3 Actual Seaming Process

(a) The hot wedge system (i.e., the "mouse" or "hot shoe") should be properly positioned for the making of the desired single or dual (split) seam.

(b) The principle of the hot wedge is that both surfaces to be joined come into intimate contact with the hot wedge, or anvil. The anvil slides between both layers of FMLs and fusion is brought about by compressing the two melted surfaces together, causing an intermingling of the polymers from both sheets. The hot anvil itself reduces the surface tension of the viscous polymer sheets and acts as a scraper/mixer, followed closely by the nip rollers which squeeze the two FML's together, see Figure 20 for details.

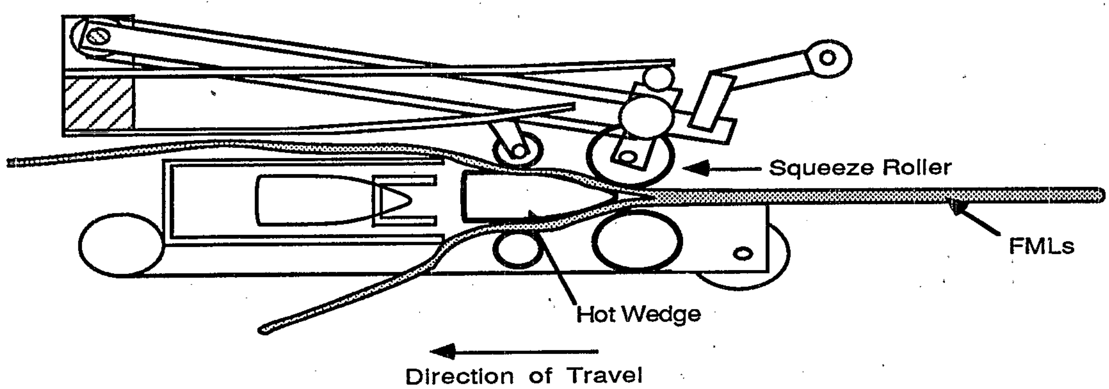


Figure 20. Details of the Hot Wedge System Showing Relative Positions of the Hot Wedge, Rollers and Sheets to be Joined.

(c) Temperature settings will vary according to the FML thickness being installed, the ambient temperature and the rate of travel. It is typically about 480°F (250°C) and is initially determined based on results of the test strip.

(d) Ambient factors such as clouds, wind, and hot sun will require the temperature setting of the wedge to vary. Depending upon the records to be kept, one might record a number of different temperatures. For example, the temperature of the hot anvil, the temperature of the sheet after seaming, the temperature of the sheet away from the seaming area and the ambient temperature. This is a site specific decision.

(e) Power for the drive motor should be off when positioning the machine to make a seam. Manually place the machine within the overlapped sheet of material. The sheets shall be guided between the idlers and the wedge, and into the drive/nip rollers. This procedure is only possible when starting with two new sheets. When starting a weld in the middle of two sheets, the material must be loaded from the sides. The machine is to be picked up a few inches, loading the bottom sheet first, and then the top sheet. As soon as the nip rollers are engaged and the wedge is in position, the power to the drive motor should be turned on. Once the sheets are between the nip rollers, they shall be engaged immediately, otherwise a melt-through will occur within a few seconds. The hot wedge should be moved into position and locked.

(f) It is necessary that the operator keep constant visual contact with the temperature controls, as well as the completed seam coming out of the machine. Occasional adjustments of temperature or speed will be necessary to maintain a consistent weld. Visual inspection and constant hand testing by the peel method (or other) is also recommended.

(g) On some soils, the device tends to "bulldoze" into the ground as it travels. This causes soil to enter the weld, making the seam weak and unacceptable. To overcome this, it is recommended that the operator take some of the weight off of the front of the machine by lifting it slightly. Alternatively, some type of base for the machine to travel on could be provided. Strips of geotextile or geomembrane have proven effective to prevent this bulldozing effect. It might be required to change the size of the rollers in loose soils. It is recommended that at least two people work together in making hot wedge seams; one operator and one helper.

7.4 After Seaming

(a) A smooth insulating plate or heat insulating fabric is to be placed beneath the hot welding apparatus after usage.

(b) A slight amount of "squeeze-out" or "flashing" is a good indicator that the proper temperatures were achieved, see the sketch of Figure 21. It signifies a proper seam in that some of the melted polymer was laterally extruded out of the seam zone. If an excessive amount of hot melt is being extruded out, it is an indication of either too much heat or too much pressure. Reduce the temperature and/or pressure to correct the situation.

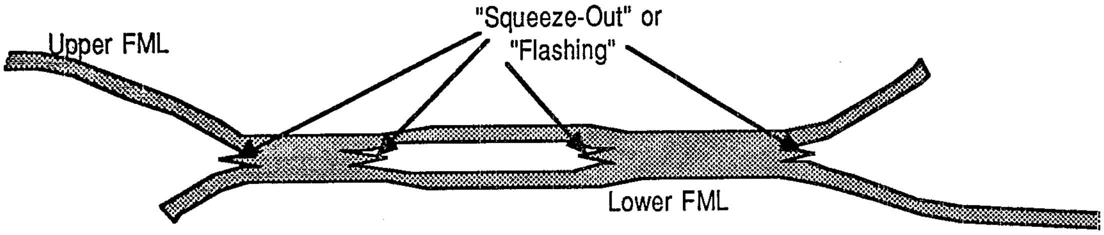


Figure 21. Schematic Diagram of Cross Section of Dual (Spilt) Hot Wedge Seam Illustrating Squeeze-Out

(c) For FMLs of 40 mil thickness and less, a long, low sinusoidal wavelength pattern in the direction of the seam along its top surface is indicative of a proper weld. If the wave peaks become too close together, the machine speed should be increased until a satisfactory pattern is present. The absence of this wavelength pattern indicates that the machine speed should be decreased. FML's 40 mils in thickness and less require considerable visual inspection. There will be no wavy pattern for FMLs greater than 40 mils in thickness due to the inherent stiffness of the thicker material.

(d) Nip/drive roller marks will always show on the surface when using knurled rollers. Their depth should be visually observable, but just barely evident to the touch.

(e) The hot wedge device has only a few adjustments that can be made, but it is very important that they be checked regularly. Cleaning of machine should be done at least daily.

(f) Photographs of cross sections of different types of hot wedge seams follow in Figure 22.

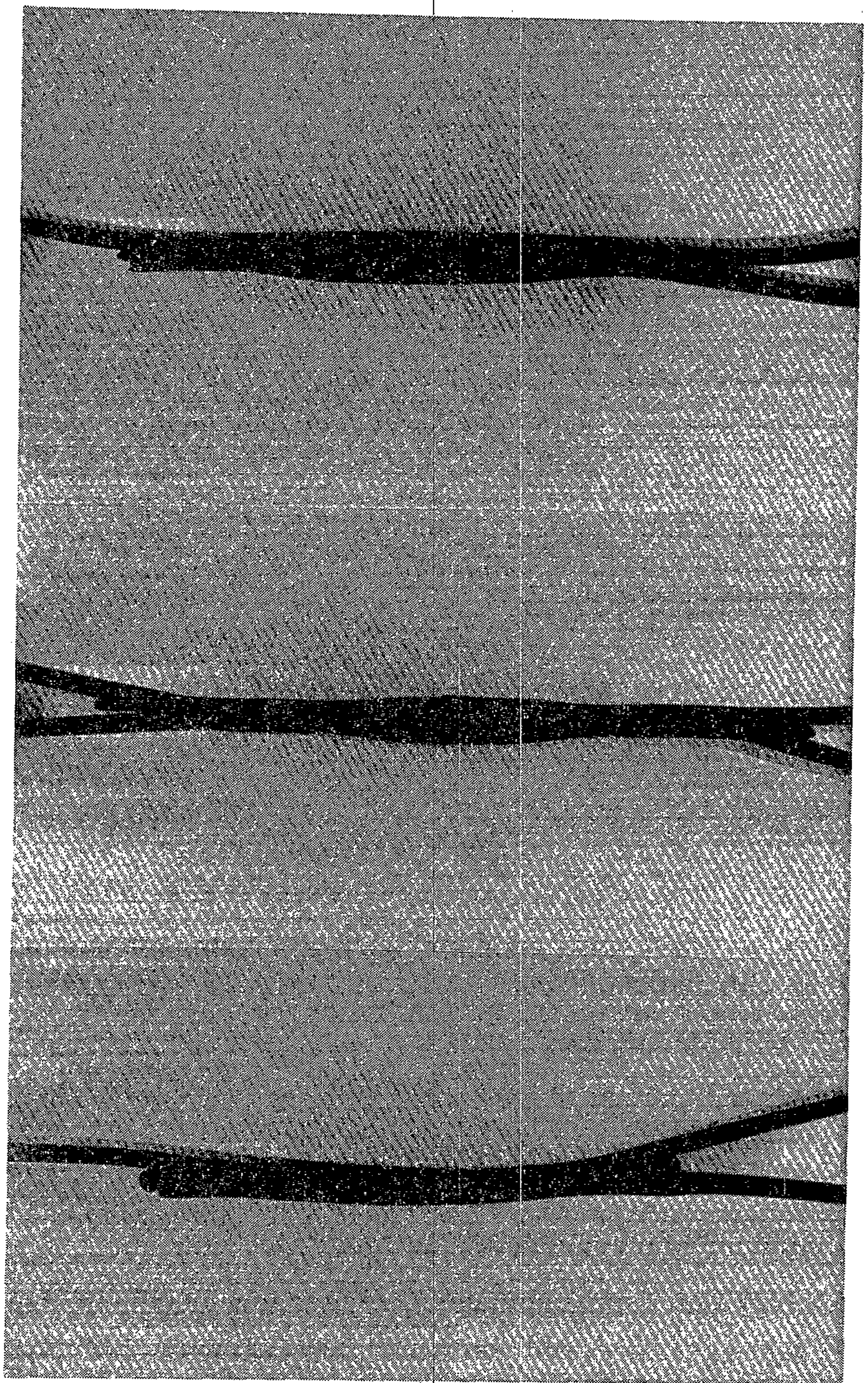


Figure 22. Photographs of Cross Sections of Hot Wedge Seams
Upper: Single Hot Wedge Seam with Acceptable Squeeze-Out
Middle: Dual Hot Wedge Seam with Excessive Squeeze-Out
Lower: Dual Hot Wedge Seam with Acceptable Squeeze-Out

8. CONCLUDING STATEMENT

The preparation and construction of polyethylene FML field seams requires a balance between adequate strength, uniform continuity, and long-term performance. The first two of these items are the usual focus of most CQC/CQA efforts. For example, removal of field seam samples are commonplace and their shear and peel testing and evaluation protocol is well established. Similarly, seam uniformity and continuity is generally evaluated by any one of a number of nondestructive test methods, the most common being the vacuum box test.

Long-term performance, however, can only be assured by treating the seam's preparation and fabrication as carefully as that of the parent sheet's preparation and manufacture. It is in this regard that this technical guidance document is written. Hopefully it falls midway between a FML installers guide and the usual CQC/CQA manual. Its goal is to aid all parties involved in polyethylene field seam fabrication, inspection and final acceptance in gaining the insight necessary to understand the processes involved. By so doing a genuine sensitivity and awareness of this critical element in the long-term performance of polyethylene FMLs will be enhanced.

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10. GLOSSARY OF TERMS

Anvil — In hot wedge seaming of FMLs, the anvil is the wedge of metal above and below which the sheets to be joined must pass. The temperature controllers and thermocouples of most hot wedge devices are located within the anvil.

Buffing — An inaccurate term often used to describe the grinding of polyethylene FMLs to remove surface oxides and waxes in preparation of extrusion seaming.

Construction Quality Assurance (CQA) — A planned system of activities whose purpose is to provide a continuing evaluation of the quality control program, initiating corrective action where necessary.

Construction Quality Control (CQC) — Actions that provide a means of controlling and measuring the characteristics of the manufactured and installed product.

Destructive Tests — Tests performed on FML samples cut out of a field installation to verify specification performance requirements, e.g., shear and peel tests of FML seams during which the specimens are destroyed.

Drive Rollers — Knurled or rubber rollers which grip the FML sheets via applied pressure and propel the seaming device at a controlled rate of travel.

Extrudate — The molten polymer which is emitted from an extruder during seaming using either extrusion fillet or extrusion flat methods. The extrudate is initially in the form of a ribbon, rod, bead or pellets.

Extruder (factory) — A stationary machine with a driver screw for continuous forming of polymeric compounds by forcing through a die. It is used to manufacture films and sheeting.

Extruder (field) — A portable device with a driver screw for continuous forming of a ribbon, rod or bead of extrudate for making FML seams.

Factory Seams — The seaming of FML rolls together to make large panels for transportation and field installation: Note that this is rarely done for polyethylene which is made in relatively wide sheets.

Field Seams — The seaming of FML rolls or panels together in the field making a continuous liner system.

Flashing — The molten extrudate or sheet material which is extruded beyond the die edge or molten edge, also called "squeeze-out".

Flexible Member Liner (FML) — Synonymous term for geomembrane as used in the containment of solid, liquid and vapor materials.

Geomembrane — An essentially impermeable membrane used as a solid, liquid or vapor barrier with foundation, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a human-made project, structure, or system. (ASTM definition)

Geotextile — Any permeable textile used with foundation, soil, rock, earth, or any other geotechnical engineering-related material as an integral part of a human-made project, structure, or system. (ASTM definition)

Grinding — The removal of oxide layers and waxes from the surface of a polyethylene sheet in preparation of extrusion fillet or extrusion flat seaming.

Gun — Synonymous term for hand held extrusion fillet device.

High Density Polyethylene (HDPE) — A polyethylene with a *resin* density, according to ASTM D3350, of 0.941 to 0.960 g/cc (see polyethylene). The FML industry, however, uses the term HDPE as being a liner with a *compound* density above 0.941 g/cc.

Hook Blade — A shielded knife blade confined in such a way that the blade cuts upward or is drawn toward the person doing the cutting.

Horn — The vibrating device used with ultrasonic seaming which vibrates at high frequency causing friction and a subsequent melting of the surfaces that it contacts.

Mouse — Synonymous term for hot wedge, or hot shoe, seaming device.

Nondestructive Test — A test method which does not require the removal of samples from, nor damage to, the installed liner system. The evaluation is done in an in-situ manner as with a vacuum box test.

Oxide Layer — The taking of atmospheric oxygen in the form of a surface film after a polyethylene sheet is extruded or otherwise manufactured.

Pinholes — Small imperfections in sheet or seamed FMLs which allow for escape of the contained material, i.e. leaks.

Polyethylene (PE) — A semicrystalline thermoplastic polymer made largely of ethylene, often incorporating lesser amounts of one or more comonomers.

Pressure Rollers — Rollers accompanying a seaming technique which apply pressure to the opposing FML sheets to be joined. They closely follow the actual melting process and are self-contained within the seaming device.

Puckering — The thermal distortion of the seamed region after completion and cooling of the seam. It is often observed on the under side of the seam.

Quality Assurance — see construction quality assurance.

Quality Control — see construction quality control.

Shielded Blade — A knife within a housing which protects the blade from being used in an open fashion, i.e. a protected knife.

Squeeze-Out — see "flashing".

Tensiometer — A set of opposing grips used to place a FML seam in tension for evaluating its strength in shear or in peel. Many units are portable and can be used in the field for direct information feed-back to the parties involved.

Test Strips — Trial sections of seamed FMLs used to establish machine setting of temperature, pressure and travel rate for a specific FML under a specific set of atmospheric conditions.

Test Welds — see "test strips".

Vacuum Box — A commonly used type of nondestructive test method which develops a vacuum in a localized region of an FML seam in order to evaluate the seam's tightness and suitability.

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